U.S. FISH AND WILDLIFE SERVICE
SPECIES ASSESSMENT AND LISTING PRIORITY ASSIGNMENT FORM

SCIENTIFIC NAME: *Quadrula cylindrica cylindrica* Say, 1817

COMMON NAME: Rabbitsfoot

LEAD REGION: 4

INFORMATION CURRENT AS OF: March 12, 2010

STATUS/ACTION (Check all that apply):

____ Species assessment – determined species did not meet the definition of endangered or threatened under the Act and, therefore, was not elevated to Candidate status
____ New candidate
_X_ Continuing candidate
 _X_ Non-petitioned
 __ Petitioned - Date petition received: ___
  ___ 90-day positive - FR date: ___
  ___ 12-month warranted but precluded - FR date: ___
  ___ Did the petition request a reclassification of a listed species?
 ___ Listing priority change
  Former LP: ___
  New LP: ___
Latest date species first became a Candidate: November 9, 2009
___ Candidate removal: Former LP: ___ (Check only one reason)
 ___ A - Taxon is more abundant or widespread than previously believed or not subject to the degree of threats sufficient to warrant issuance of a proposed listing or continuance of candidate status.
 ___ F - Range is no longer a U.S. territory.
 ___ I – Insufficient information exists on biological vulnerability and threats to support listing.
 ___ M - Taxon mistakenly included in past notice of review.
 ___ N - Taxon may not meet the Act's definition of "species."
 ___ X - Taxon believed to be extinct.

ANIMAL/PLANT GROUP AND FAMILY
Clams and Mussels/Unionidae

HISTORICAL STATES/TERRITORIES/COUNTRIES OF OCCURRENCE
Alabama, Arkansas, Georgia, Indiana, Illinois, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Oklahoma, Ohio, Pennsylvania, Tennessee, West Virginia

CURRENT STATES/COUNTIES/TERRITORIES/COUNTRIES OF OCCURRENCE
Alabama, Arkansas, Indiana, Illinois, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Oklahoma, Ohio, Pennsylvania, Tennessee

LAND OWNERSHIP
The majority of land ownership in watersheds with extant rabbitsfoot stream populations is privately owned, particularly those lands in riparian corridors (possibly 95 percent). The Nature Conservancy (TNC) has established bioreserves along several stream systems harboring extant populations of the rabbitsfoot (e.g., Green, Tippecanoe, Paint Rock, Duck, Strawberry Rivers; Fish, Big/Little Darby Creeks).

Approximately five percent of land that occurs along historical and extant streams of occurrence for the rabbitsfoot or in their respective watersheds is in public ownership (e.g., state, national parks and forests; wildlife management areas). Following are some of the more significant public lands associated with important rabbitsfoot populations. The Allegheny and Buffalo (Arkansas) Rivers and Big and Little Darby Creeks have been designated National Wild and Scenic Rivers. Numerous other streams with rabbitsfoot populations have been designated state scenic rivers (e.g., Duck, Illinois Rivers). The location of Mammoth Cave National Park (MCNP) in the upper Green River provides a significant level of localized watershed protection for the rabbitsfoot population in that system.

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BIOLOGICAL INFORMATION

<u>Description</u>

The rabbitsfoot (*Quadrula cylindrica cylindrica* Say 1817) was originally described from the type locality in the Wabash River. The rabbitsfoot is a medium to large-sized mussel that reaches about six inches in length. Key characters useful for distinguishing it from other mussels include its elongated shape, sculpture, and color pattern. The shell shape is elongate, rectangular and moderately inflated in mature specimens. The beaks (umbos; oldest part of the shell) are low, located anteriorly, and barely extend above the hingeline. Beak sculpture consists of a few strong ridges or folds continuing onto the newer growth of the umbo as small tubercles. Shell sculpture consists of a few large, rounded, low tubercles on the posterior slope, although some individuals will have numerous small, elongated pustules particularly anteriorly. The periostracum (external shell surface) is generally smooth and yellowish, greenish, or olive in color becoming darker and yellowish-brown with age and usually covered with dark green or nearly black chevrons and triangles pointed ventrally (Say 1817, p. 13). These patterns are absent in some individuals. Growth rest periods (age rings) appear as grooves in the shell (Oesch 1984, p. 91).

Internally, the color of the nacre (mother-of-pearl) is white and iridescent, often with a gray-green tinge in the umbo cavity. Specimens from the southern periphery of its range are occasionally purplish. Soft parts generally have an orangish color (Parmalee and Bogan 1998, pp. 211-212; Oesch 1984, p. 91). However, Vidrine (1993, p. 55) noted that the rabbitsfoot in the Ouachita River system in Louisiana had black soft parts. Aspects of the soft anatomy are described by Ortmann (1912, pp. 256-257), Utterback (1915, pp. 148-149), Davis and Fuller (1981, pp. 228-233 and 241), and Oesch (1984, p. 91).

Taxonomy

A member of the freshwater mussel family Unionidae, the rabbitsfoot was originally described as *Unio cylindrica* (Say, 1817, no pagination but p. 13 of publication). The type locality is the Wabash River (Parmalee and Bogan 1998, p. 210), probably in the vicinity of New Harmony, Posey County, Indiana, and adjacent Illinois, where Thomas Say lived. Parmalee and Bogan (1998, p. 210) summarized the synonomy of the rabbitsfoot. The rabbitsfoot has been considered a member of the genera *Unio*, *Mya*, *Margarita*, *Margaron*, and *Orthonymus* at various times in history. It was first considered a member of the genus *Quadrula* by Lewis (1870, p. 218). The description of *U. cylindricus strigillatus* B.H. Wright, 1898 (=*Q. cylindrica strigillata*, the federally endangered rough rabbitsfoot; Turgeon et al. 1998), rendered the rabbitsfoot, *Q. c. cylindrica*, as a subspecies for *Q. cylindrica*.

Davis and Fuller (1981, p. 241) conducted a taxonomic study on the rough rabbitsfoot (*Q. c. strigillata*) and suggested that it was different enough from other *Quadrula* species based on three soft anatomy characters to warrant separate generic status, the monospecific genus *Orthonymus* (Agassiz, 1852). In an unpublished report, Clarke and Obermeyer (1996) thought *Orthonymus* should be relegated to subgeneric status under *Quadrula*. Further, they did not consider the *Quadrula cylindrica strigillata* and *Q. c. cylindrica* to be valid subspecies but considered the rough rabbitsfoot to be “a highly sculptured and compressed morph of [rabbitsfoot].” Sproules et al. (2006, p. 3) conducted a genetic analysis of 32 rabbitsfoot from the Duck River (Tennessee), Illinois River (Arkansas), Green River (Kentucky), and Ouachita River (Arkansas) and seven rough rabbitsfoot (*Q. c. strigillata*) from the Clinch River (Tennessee). Their results also indicated that the smooth and rough forms of the rabbitsfoot may not represent separate taxonomic entities and none of the populations could be considered an evolutionarily significant unit, but neither result could be validated without further study and statistical analyses (Sproules 2006, pp. 8-10). Clarke and Obermeyer (1996) nor Sproules (2006) results and “opinion” have been published in a peer-reviewed scientific journal. Vidrine (1993, p. 55) noted that the rabbitsfoot in Louisiana (Ouachita River system) had “black flesh” and implied that this population may warrant its own genus.

Although discussion continues over the taxonomic status of the rabbitsfoot, the designation of the rabbitsfoot as a species does not affect its qualification for listing as a subspecies under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.).

Careful review of the rabbitsfoot's taxonomic information confirms it is a valid subspecies. Both subspecies are currently deemed valid by the Committee on Scientific and Vernacular Names of Mollusks of the Council of Systematic Malacologists and the American Malacological Union (Turgeon et al. 1998, p. 37). The American Fisheries Society (AFS) Committee on Names of Aquatic Invertebrates was established in 1981 and is responsible for studying and reporting on matters concerning common and scientific names of aquatic invertebrates and prepares a checklist of names to achieve uniformity and avoid confusion in nomenclature. The Committee is the custodian of the master checklists and coordinates with those of other societies and organizations throughout the world. Turgeon et al. (1998) was compiled by a committee of experts and names were published based on majority rule and AFS principles governing the selection of common names. Scientific names are based on careful review of scientific literature. No other publications exist to dispute scientific literature on nomenclature for this subspecies reviewed for Turgeon et al. (1998), making it the recognized leading source for nomenclature recognition on the rabbitsfoot at this time.

Habitat

Parmalee and Bogan (1998, pp. 211-212) described the following habitat requirements for the rabbitsfoot. The rabbitsfoot is primarily an inhabitant of small to medium-sized streams and some larger rivers. It usually occurs in shallow areas along the bank and adjacent runs and shoals where the water velocity is reduced. Specimens may also occupy deep water runs, having been reported in 9-12 feet of water. Bottom substrates generally include sand and gravel. This species seldom burrows but lies on its side (Watters 1988, p. 13; Fobian 2007, p. 24).

Strayer (1999a, pp. 468 and 472) thought that features commonly used in the past to explain the spatial patchiness of mussels (e.g., water depth, current speed, sediment grain size) were poor predictors of where mussels actually occur in streams. He demonstrated in field trials that mussels in streams occur chiefly in flow refuges, or relatively stable areas that displayed little movement of substrate particles during flood events. Other researchers have also come to the conclusion that mussel beds occur in areas where shear stresses are low and sediments remain stable during flooding (Layzer and Madison 1995, p. 341; Hastie et al. 2001, pp. 111-114). Flow refuges conceivably allow relatively immobile mussels such as the rabbitsfoot to remain in the same general location throughout their entire lives. These patches of stable habitat may be highly important for the rabbitsfoot since it typically does not burrow, making it more susceptible to displacement into unsuitable habitat. However, flow refuges are not created equal and there are likely other habitat variables that are important, but poorly understood (A. Roberts 2008, personal communication (pers. comm.)).

Life History

Biological information specific to this species is sparse, but general information known about other freshwater mussels applies to this taxon.

Food habits – Adult freshwater mussels have long been considered suspension-feeders, siphoning phytoplankton, diatoms, and other microorganisms from the water column (Fuller 1974, p. 221). Recent evidence emphasizes the importance of the uptake and assimilation of detritus and bacteria over that of algae to riverine mussels (Silverman et al. 1997, pp. 1862-1865; Nichols and Garling 2000, pp. 874-876). It has also been surmised that dissolved organic matter may be a significant source of nutrition (Strayer et al. 2004, p. 430). Their diet may more accurately consist of a mixture of algae, bacteria, detritus, and microscopic animals. Such an array of foods--containing essential long-chain fatty acids, sterols, amino acids, and other biochemicals--may be necessary to supply total nutritional needs (Strayer et al. 2004, pp. 430-431). For their first several months, juvenile mussels employ foot (pedal) feeding and are thus deposit feeders, although they may also filter interstitial pore water (Yeager et al. 1994, p. 221).

Growth and longevity – Growth rates for mussels tend to be relatively rapid for the first few years (Chamberlain 1931; Scruggs 1960, pp. 28-30; Negus 1966, pp. 517-518) then slow appreciably (Bruenderman and Neves 1993, p. 88; Hove and Neves 1994, pp. 34-36). The relatively abrupt slowing in growth rate occurs at sexual maturity, probably as a result of energy being diverted from growth to gamete production (Baird 2000, pp. 63-71). Growth rates vary among species; heavy-shelled species grow slowly relative to thin-shelled species (Coon et al. 1977, pp. 19-21; Hove and Neves 1994, p. 38).

No quantitative information on the longevity of the rabbitsfoot is available, although data is available for the rough rabbitsfoot. Yeager and Neves (1986, p. 332) subjectively aged (by counting external growth rings) the rough rabbitsfoot to 22 years, and Henley et al. (no date, p. 16) objectively aged (by thin-sectioning shells) a specimen at 63 years. Interestingly, Anthony et al. (2001, pp. 1352-1357) surmised that growth ring counts (from direct measurements of field-marked individuals) may not be annual and that researchers may actually be underestimating longevity by a factor of 3 to 10. This might mean that the some mussels (possibly including the rabbitsfoot) may live for centuries (Strayer et al. 2004, p. 433). However, Strayer et al. (2004, p. 433) recognized that until the discrepancy between growth rates estimated from direct measurements and those inferred from shell rings is resolved, studies of mussel growth should verify the accuracy of the aging method by independent means.

Reproductive biology – Sex ratios in mussels generally do not differ significantly from 1:1, although some *Quadrula* populations tend to be male-biased (Haag and Staton 2003, p. 2122). Age at sexual maturity for the rabbitsfoot is 4 to 6 years for populations in the upper Arkansas, White, and Red River Systems (Fobian 2007, p. 50). Rabbitsfoot exhibit seasonal movement migrating toward shallower water during brooding periods (Fobian 2007, p. 48). Males expel clouds of sperm into the water column, which are drawn in by females through their incurrent siphons. Fertilization takes place internally, and the resulting zygotes develop into specialized larvae termed glochidia within the female's gills. Fertilization success is apparently influenced by mussel density and flow conditions (Downing et al. 1993, pp. 153-154). This potentially indicates that small populations occurring in low-flow streams (or in streams experiencing drought conditions during the reproductive period) may experience reduced fertilization rates.

Similar to other species of *Quadrula*, the rabbitsfoot utilizes all four gills as a marsupium (pouch) for its glochidia (Howard 1914, N.L. Eckert 2005, pers. comm.). It is a short-term brooder, with females brooding between May and late August (Fobian 2007, pp. 15-16) in the upper Arkansas, White, and Red River Systems. Fobian (2007, p. 48) also observed differences in morphology and reproductive timing indicating that the populations in the upper Arkansas, White, and Red River Systems should be managed as separate units. Hermaphroditism (presence of both male and female reproductive organs) occurs in many mussel species (van der Schalie 1966, pp. 77-78) but is generally not known for the rabbitsfoot. If hermaphroditism does occur in the rabbitsfoot, it may explain the occurrence of small but persistent populations over long periods of time in some parts of its range.

From parasitic glochidia to free-living juveniles – The larvae of the family Unionidae are specialized for a parasitic existence, and referred to as glochidia. Female mussels of the genus *Quadrula* commonly release glochidia packaged in the form of conglutinates. Conglutinates are gelatinous (jellylike) matrices holding numerous glochidia together, and also numbers of embryos and undeveloped ova. The lanceolate (lance shaped) conglutinates of the rabbitsfoot, presumably depending on the development rates of their ova and encapsulated glochidia, are yellowish-brown or pale orange (Ortmann 1919). They may mimic flatworms or similar fish prey. Fecundity (capacity of abundant production) in the upper Arkansas, White, and Red River Systems ranged from 46,000 to 169,000 larvae per female (Fobian 2007, p. 19).

Rabbitsfoot glochidia are gill parasites and measure approximately 0.0074 inches in both length and height (Ortmann 1919). Yeager and Neves (1986, p. 333) noted a diagnostic reddish-brown tinge on the mantle of rough rabbitsfoot glochidia. Glochidia remain viable for a week or two (Zimmerman and Neves 2002, pp. 33-34) and must come into contact with a specific host fish(es) for their survival to be ensured.

Hosts for the rabbitsfoot have been investigated for populations west of the Mississippi River. Blacktail shiner (*Cyprinella venusta*) from the Black and Little River and cardinal shiner (*Luxilus cardinalis*), red shiner (*C. lutrensis*), spotfin shiner (*C. spiloptera*), and bluntface shiner (*C. camura*) from the Spring River were suitable hosts (Fobian 2007, p. ii). Rosyface shiner (*Notropis rubellus*), striped shiner (*L. chrysocephalus*), and emerald shiner (*N. atherinoides*) served as hosts for rabbitsfoot, but not in all stream populations tested (Fobian 2007, p. 69). The hosts for the rabbitsfoot include shiners (genus *Cyprinella*, *Luxilus*, *Notropis*) for populations west of the Mississippi River, but host suitability trials are still needed for the eastern range.

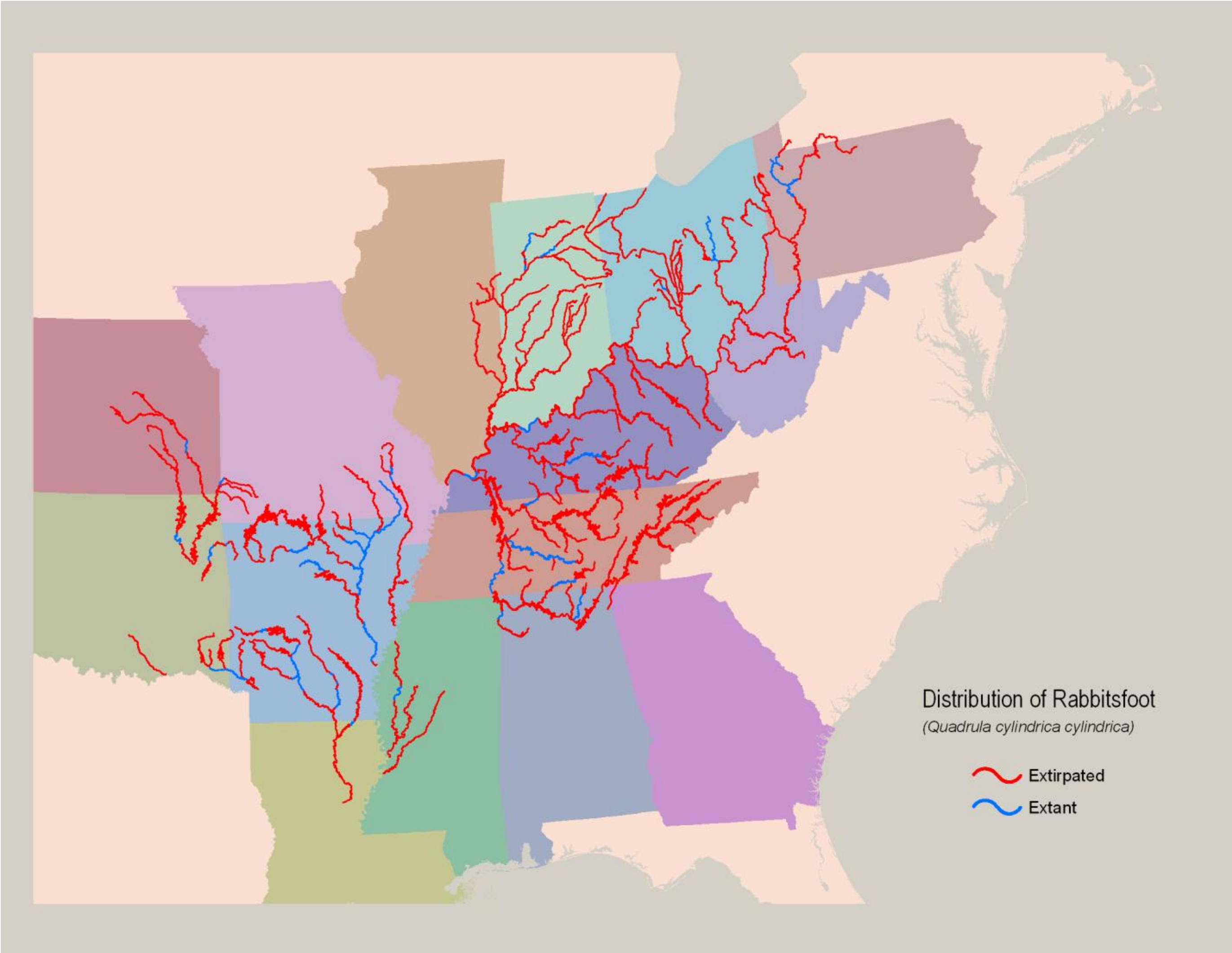
Glochidia generally spend from two to six weeks parisitizing the host fish, the duration of encystment being dependent on the mussel species and water temperature (Zimmerman and Neves 2002, pp. 33-34). Newly-metamorphosed juveniles drop off to begin a free-living existence on the stream bottom. They must drop into suitable habitat or they will die. The fact that rabbitsfoot populations are oftentimes highly aggregated with apparently many even-aged individuals indicates that glochidia may excyst simultaneously from a host (Fobian 2007, pp. 13 and 19-20). They also exhibit seasonal movement towards shallower water during brooding periods, a strategy to increase host fish exposure but one that also leaves them increasingly vulnerable to predation and fluctuating water levels, especially downstream of dams (Fobian 2007, pp. 48-49; C. Barnhart 2008, pers. comm.).

Historical and Current Distribution

The rabbitsfoot was historically known from 139 streams within the lower Great Lakes Sub-basin and Mississippi River Basin. The historical range included 15 states: Alabama, Arkansas, Georgia, Illinois, Indiana, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Ohio, Oklahoma, Pennsylvania, Tennessee, and West Virginia. Rabbitsfoot populations are considered to be extant in 50 streams in 13 states (Butler 2005; Matthews 2007; C. Boeckman 2008, pers. comm.; T. Smith 2008, pers. comm.; EAA 2008) (Figure 1).

Extant populations occur in the following states (with streams): **Alabama** (Paint Rock River, Bear Creek), **Arkansas** (White River, War Eagle Creek, Buffalo River, Black River, Current River, Spring River, South Fork Spring River, Strawberry River, Middle Fork Little Red River, Illinois River, Cossatot River, Little River, Ouachita River, Little Missouri River, Saline River), **Illinois** (Ohio River, North Fork Vermilion River, Middle Branch North Fork Vermilion River), **Indiana** (Ohio River, Eel River, Tippecanoe River), **Kansas** (Neosho River, Spring River), **Kentucky** (Ohio River, South Fork Kentucky River, Green River, Barren River, Rough River, Red River, Tennessee River), **Louisiana** (Bayou Bartholomew), **Mississippi** (Bear Creek, Big Sunflower River, Big Black River), **Missouri** (St. Francis River, Spring River [Arkansas River system]), **Ohio** (Fish Creek, Walhonding River, Killbuck Creek, Muskingum River, Big Darby Creek, Little Darby Creek), **Oklahoma** (Illinois River, Little River, Glover River, Verdigris River), **Pennsylvania** (Allegheny River, French Creek, Muddy Creek, LeBoeuf Creek, Conneautee Creek), and **Tennessee** (East Fork Stones River, Red River, Tennessee River, Elk River, Duck River).

Figure 1. March, 2010, distribution of Rabbitsfoot (*Quadrula cylindrica cylindrica*)



Populations of the rabbitsfoot were generally considered extant if live (L) or fresh dead (FD) specimens have been collected since about 1985 unless subsequent sampling efforts indicated otherwise. The rabbitsfoot historically occurred in the following drainage basins and streams:

Lower Great Lakes Sub-basin (6 streams):

1. Maumee River (extirpated circa 1960)

2. St. Joseph River (extirpated circa 1970)

3. Fish Creek (restricted to lower most reach, 4 river miles)

4. Feeder Canal (extirpated circa 1920)

5. St. Marys River (extirpated circa 1920)

6. Auglaize River (extirpated mid 1900s)

Ohio River system (65 streams):

1. Ohio River (historically occurred throughout most of 981 river miles; very small extant populations restricted to lower most section of river [river miles unknown] and best population near Lock and Dam 52 and 53 which includes 16 river miles)

2. Allegheny River (historically occurred throughout >100 river miles; 8 sporadic extant sites from Armstrong County upstream to Warren County)

3. French Creek (historically occurred along 117 river miles; extant in 80 river miles)

4. LeBoeuf Creek (thought to be restricted to lower 0.75 river mile as no data exists on other occurrences; only historical occurrence in same reach)

5. Muddy Creek (thought to be restricted to lower 4 river miles as no data exists on other occurrences; only historical occurrence in same reach)

6. Conneautee Creek (thought to be restricted to lower 0.75 river mile as no data exists on other occurrences; only historical occurrence in same reach)

7. Monongahela River (extirpated circa 1890s)

8. West Fork River (extirpated circa 1910)

9. Beaver River (extirpated circa 1900)

10. Shenango River (extirpated circa 1990s)

11. Pymatuning Creek (extirpated circa 1910)

12. Mahoning River (extirpated unknown; one undated museum record)

13. Muskingum River (2 live specimens collected at one site in 2007 near river mile 92 near Dresden, Muskingum County, OH; believed extirpated from the river circa 1980 until 2007 record)

14. Tuscarawas River (extirpated circa 1990s)

15. Walhonding River (historically occurred along 23 river miles; extant in 12 river miles)

16. Killbuck Creek (extant in lower reach; river miles unknown)

17. Mohican River (extirpated circa 1980)

18. Black Fork Mohican River (extirpated pre-1990)

19. Little Kanawha River (extirpated circa early 1900s)

20. Elk River (extirpated unknown; one relict)

21. Big Sandy River (extirpated 1800s)

22. Levisa Fork (extirpated circa 1910)

23. Scioto River (extirpated circa 1970)

24. Olentangy River (extirpated circa mid 1960s)

25. Whetstone Creek (extirpated pre 1930)

26. Big Walnut Creek (extirpated circa mid 1960s)

27. Alum Creek (extirpated 1800s)

28. Walnut Creek (extirpated pre 1990)

29. Big Darby Creek (extant at one site)

30. Little Darby Creek (extant in 20 river miles, but sporadic in 10 of 20 river miles)

31. Deer Creek (extirpated pre 1980)

32. Ohio Brush Creek (extirpated 1970s)

33. Little Miami River (extirpated circa 1900)

34. Licking River (extirpated pre 1990)

35. South Fork Licking River (extirpated pre 1980)

36. Kentucky River (extirpated circa 1920)

37. South Fork Kentucky River (restricted to one site)

38. Salt River (extirpated pre 1980)

39. Green River (historically occurred along 150 river miles; extant along 100 river miles)

40. Russell Creek (extirpated circa 1910)

41. Nolin River (extirpated 1980s)

42. Barren River (extant at one site 10 river miles downstream of Barren River Reservoir)

43. Drakes Creek (extirpated circa 1930s)

44. West Fork Drakes Creek (extirpated circa 1930s)

45. Rough River (only FD specimens reported since 1993, doubtful if population is extant)

46. Wabash River (once abundant in this 475 mile river, possibly extant at one site, but has not been collected L since 1988; functionally extirpated)

47. Mississinewa River (extirpated pre 1990)

48. Eel River (extant at two sites in lower 20 river miles)

49. Tippecanoe River (extant in lower 50 river miles, but highly disjunct in lower two-thirds)

50. Vermilion River (extirpated pre 1990)

51. North Fork Vermilion River (extant at 4 sites in lower 6 river miles)

52. Middle Branch North Fork Vermilion River (extant at two sites in lower most section, population considered contiguous with North Fork Vermilion River)

53. Middle Fork Vermilion River (extirpated circa 1920)

54. Salt Fork Vermilion River (extirpated circa 1920)

55. Sugar Creek (extirpated circa 1940s)

56. Embarras River (extirpated pre 1980s)

57. White River (extirpated circa 1960s)

58. East Fork White River (extirpated pre 1990)

59. Driftwood River (extirpated circa 1940s)

60. Big Blue River (extirpated early 1900s)

61. Brandywine Creek (extirpated pre 1990)

62. Sugar Creek (extirpated pre 1990)

63. Flatrock River (extirpated mid 1900s)

64. West Fork White River (extirpated pre 1990)

65. Black Creek (extirpated unknown date)

Cumberland River system (13 streams):

1. Cumberland River (extirpated circa 1980)

2. Rockcastle River (extirpated circa early 1900s)

3. Big South Fork (extirpated circa early 1900s)

4. Beaver Creek (extirpated circa 1950s)

5. Obey River (extirpated circa mid 1900s)

6. East Fork Obey River (extirpated unknown date)

7. Caney Fork (extirpated between 1961 and 1981)

8. Stones River (extirpated circa 1970s)

9. East Fork Stones River (historically 45 river miles plus; only FD specimens from 2 sites since 1985)

10. West Fork Stones River (extirpated circa 1960)

11. Harpeth River (extirpated circa late 1800s)

12. Red River (historically from a few sites in Kentucky and Tennessee, but not thoroughly surveyed and status is unknown, extant at one site in TN)

13. Whippoorwill Creek (extirpated pre 1980s)

Tennessee River system (19 streams):

1. Tennessee River (historically throughout most of river; extant in 2 lower most tailwaters below Pickwick Landing Dam and Kentucky Dam, approximately 25 river miles)

2. Holston River (extirpated circa 1920)

3. French Broad River (extirpated unknown date)

4. Little Pigeon River (extirpated unknown date)

5. Little Tennessee River (extirpated unknown date)

6. Clinch River (extirpated circa 1940s)

7. Lookout Creek (extirpated circa late 1970s)

8. Sequatchie River (extirpated circa early 1900s)

9. Paint Rock River (extant in lower 56 river miles)

10. Hurricane Creek (extirpated circa 1990s)

11. Estill Fork (extirpated pre 1970)

12. Larkin Fork (extirpated circa 1970s)

13. Flint River (extirpated mid 1960s)

14. Elk River (extant at possibly six sites in Tennessee, but in imminent danger of extirpation)

15. Shoal Creek (extirpated pre 1990)

16. Bear Creek (historically occurred along 45 river miles; extant along 4 river miles)

17. Duck River (historically common along 200 river miles; extant population concentrated between river mile 130-179 and sporadic between river mile 30-130)

18. Big Rock Creek (extirpated pre 1990)

19. Buffalo River (extirpated circa 1970s)

Lower Mississippi River Sub-basin (5 streams):

1. St. Francis River (historically occurred throughout >100 river miles; extant along approximately 20 river miles in Missouri)

2. Big Creek (extirpated circa 1980s)

3. Yazoo River (extirpated unknown date)

4. Big Sunflower River (extant in 20 river miles upstream of Indianola, Mississippi)

5. Big Black River (historically occurred along 15 plus river miles; probably not extant with only FD individuals being collected in 1980-1981 and one dead specimen in 2000)

White River system (12 streams):

1. White River (historically occurred throughout most of the 690 mile main stem; two extant population clusters each 50-55 river miles in length but separated by 100 river miles)

2. War Eagle Creek (first discovered in several mile reach in 1974; only FD individuals found in 2004)

3. Buffalo River (historically occurred along approximately 100 river miles; a small extant population exists in the upper reaches but restricted to only a few sites)

4. North Fork White River (extirpated circa 1920)

5. Black River (historically abundant along most of river; extant population remains locally abundant, but in decline)

6. Current River (L/FD specimens first reported between river mile 31-38 in early 1980's; only relict specimens collected since then, questionable if extant population persists)

7. Spring River (historically abundant along 50 plus river miles; extant but in decline in same reach)

8. South Fork Spring River (numerous FD shells from one site in 2002; questionable if extant, but if extant very restricted distribution).
9. Strawberry River (historically occurred along approximately 50 river miles; extant and still abundant in same reach)

10. Little Red River (extirpated circa 1970)

11. Middle Fork Little Red River (first surveyed in 1992; extant at 4 of 28 sites, restricted to lower reaches, and sometimes locally abundant)

12. Reeses Fork Cache River (extirpated circa 1980s)

Arkansas River system (8 streams):

1. Verdigris River (historic distribution unknown; extant in 5 river miles)

2. Fall River (extirpated circa early 1900s)

3. Neosho River (historically occurred along most of 460 river miles; extant in an 8 mile reach from Iola to Humboldt, Kansas)

4. Cottonwood River (extirpated pre 1990)

5. Spring River (historic distribution unknown; extant in 15 river miles upstream of Turkey Creek confluence)

6. Center Creek (extirpated circa 1920)

7. Shoal Creek (extirpated pre 1990)

8. Illinois River (historic distribution unknown; extant at two disjunct sites in Oklahoma and 2 sites in the 30 river mile reach in Arkansas)

Red River system (11 streams):

1. Blue River (extirpated early 1900s)

2. Little River (river is 217 river miles in length and historic distribution unknown; extant population occurs in 25 river miles between Idabel and Goodwater, Oklahoma, and approximately 35-40 river miles in Arkansas from the Arkansas/Oklahoma stateline to Millwood Lake)

3. Glover River (historically occurred in 20-30 river miles; extant at two sites separated by several river miles)

4. Mountain Fork Little River (extirpated circa 1970)

5. Cossatot River (historic distribution unknown, but documented from lower section of river in 1970 and 1983; questionable if extant, but lacking survey data)

6. Ouachita River (historically widespread throughout most of 605 river miles; extant between River Miles 339 – 376, 9 river miles in Hot Spring County, Arkansas, 10 river miles in Clark County, Arkansas, and 12 river miles in Montgomery County, Arkansas)

7. Caddo River (extirpated pre 1985)

8. Little Missouri River (historic distribution unknown; extant at one site in lower 10 river miles)

9. Saline River (historically occurred in 150 plus river miles; extant at 3 of 147 mussel beds in 102 river miles from Benton to Warren, Arkansas, and the sites occurred within 3 river miles of each other; extant at 11 of 83 mussel beds in 50 river mile segment downstream of Warren, Arkansas)

10. North Fork Saline River (extirpated pre 1985)

11. Bayou Bartholomew (historic distribution unknown, but most likely included Arkansas and Louisiana; extant at three sites in the middle portion of the river in Louisiana)

Based on historical and current data, the rabbitsfoot is declining range wide and is now extant only in 50 of 139 streams of historical occurrence, representing a 64% decline (Figure 1). Further, in the streams where it is extant, populations with few exceptions are highly fragmented and restricted to short reaches.

To conceptualize a clearer picture of the general status of extant populations, Butler (2005, pp. 89-90) grouped them into three categories: 1) sizable populations with ample evidence of recent recruitment and currently considered long-term viable for several decades to come; 2) small populations with limited levels of recent recruitment, generally highly restricted in distribution, of doubtful or limited viability, and susceptible to extirpation in the foreseeable future; and 3) marginal populations that are considered very rare, with no evidence of recent recruitment, of doubtful viability, and may be on the verge of extirpation in the immediate future.

1) *Sizable populations (11 streams)*: Ohio River (Lock & Dam 52 and 53 tailwaters), French Creek, Green River, Tippecanoe River, Tennessee River (Kentucky Dam tailwaters), Duck River, Paint Rock River, White River, Black River, Strawberry River, and Little River.

2) *Small populations (18)*: Muddy Creek, Walhonding River, Little Darby Creek, North Fork Vermilion River, Middle Branch North Fork Vermilion River, Bear Creek, St. Francis River, Big Sunflower River, Big Black River, Buffalo River,

Spring River (White River system), South Fork Spring River, Middle Fork Little Red River, Neosho River, Spring River (Arkansas River system), Verdigris River, Ouachita River, and Saline River.

3) *Marginal populations (21)*: Fish Creek, Allegheny River, LeBoeuf Creek, Conneautee Creek, Killbuck Creek, Muskingum River, Big Darby Creek, South Fork Kentucky River, Barren River, Rough River, Eel River, East Fork Stones River, Red River, Elk River, Illinois River, War Eagle Creek, Current River, Glover River, Cossatot River, Little Missouri River, and Bayou Bartholomew.

All of the stream populations in the first category and many in the second one are crucial for assessing and maintaining the rabbitsfoot's current conservation status. More importantly, many of these populations will be critical for recovery. Records indicate that 9 of the 21 streams with marginal populations are represented by a single recent L/FD specimen (i.e., Muskingum River, South Fork Kentucky, Barren, Rough, East Fork Stones, Red, Little Missouri Rivers; Big Darby Creek, Conneautee Creek). Few populations in this category are likely to play important roles in its conservation and recovery, and then only through aggressive habitat restoration and population augmentation programs.

The rabbitsfoot is believed extirpated from Georgia and West Virginia, while its continued existence in several other states (e.g., Alabama, Kansas, Louisiana, Mississippi, and Missouri) is extremely perilous. Three of the best populations, the Black River in Arkansas, the Little River in Arkansas and Oklahoma, and the Paint Rock River in Alabama are among several streams that have demonstrably declining populations (e.g., marginal populations in the Barren River in Kentucky, East Fork Stones and Elk Rivers in Tennessee, Glover River in Oklahoma, Fish and Big Darby Creeks in Ohio; small populations in the St. Francis River in Missouri, Current and Spring Rivers in Arkansas [White River system], and Little Darby Creek in Ohio). Even though we have less trend data on most of the other extant populations, the sporadic collections that are available over the past century tend to indicate population declines in other streams as well (e.g., Allegheny River in Pennsylvania, Walhonding in Ohio, Cossatot and Buffalo Rivers in Arkansas, and Bear Creek in Alabama). The available data indicates that increasing threats have resulted in population extirpations in various streams during the past several decades. Additional extirpations will occur if threats to these populations are not minimized or alleviated in order to arrest or reverse downward population trends. Further, considering the prevalence and magnitude of current threats, no extant stream population anywhere of this species is completely safe from suffering population declines and potentially extirpations at some point in the future.

Butler (2005, pp. 18-88) provides a more detailed description of streams with extant populations prior to July, 2005. A request was sent in February, 2008, to the unio list server requesting recent information on the species since Butler's (2005) assessment. Subsequent requests were sent in January, 2009, and February, 2010, to the unio list server requesting current information on the species. The Service received 63 responses to these data requests. As a result, annual data requests have been valuable in our continuing assessment of rabbitsfoot distribution and status.

DISTINCT POPULATION SEGMENT (DPS): N/A

THREATS

Butler (2005, pp. 92-120) provides a comprehensive summary of past and current threats and how these threats impact freshwater mussel populations. Many of these past threats substantially diminished rabbitsfoot populations from its historical distribution and abundance. The following five factor analysis only addresses factors presently affecting (or likely to impact) extant rabbitsfoot populations. The threats matrix provided later in the assessment provides a summary of stressors (magnitude and immediacy) affecting extant rabbitsfoot populations.

A. <u>The present or threatened destruction, modification, or curtailment of its habitat or range</u>.

The reduction of habitat and range of the rabbitsfoot has been attributed to impoundment, sedimentation, agricultural pollutants and lead and zinc mining. Numerous dams have been constructed that have impounded significant portions of the historic range of the rabbitsfoot, effectively resulting in fragmented populations and habitats. The species does not tolerate impounded conditions, and has not been collected from impounded portions of its historic habitat. In addition, it is believed that the operation of these dams will continue to negatively affect the rabbitsfoot due to thermal tolerances and channel instability (i.e., bank scouring) associated with fluctuations in flow.

Sediment sources within the current range of the rabbitsfoot include mining activity; cultivated fields; clearing of stream side buffers that result in stream bank erosion; cattle grazing; and urban, suburban, and rural construction activities. Excessive sedimentation is known to cause direct mortality of freshwater mussels by deposition and suffocation (Ellis 1936, pp. 29-42) and can eliminate or reduce the recruitment of juvenile mussels (Negus 1966, pp. 513-532; Brim-Box and Mossa 1999, pp. 99-102). High suspended sediment levels can also interfere with feeding activity (Dennis 1984, summary of 171 page dissertation). Sediment levels within the range of the rabbitsfoot are higher than historic levels and are likely to increase.

Nutrients, usually phosphorus and nitrogen, can emanate from agricultural, urban, and suburban runoff, including cultivated fields and pastures, livestock feedlots, leaking septic tanks, and residential lawns at levels that result in eutrophication and reduced oxygen levels. Eutrophication, caused by the introduction of excess nutrients to a water body, has been shown to result in periodic low dissolved oxygen levels that are detrimental to mussels (Sparks and Strayer 1998, pp. 131-133). Excess nutrients also promote heavy growth of blue-green and other algae that can eliminate habitat for juvenile mussels.

Butler (2005, pp. 101-107) summarized the effects of contaminants on mussels in part as follows:

> *The effects of contaminants (e.g., metals, chlorine, ammonia) are especially profound on juvenile mussels (Robison et al. 1996, Jacobson et al. 1993, Bartsch et al. 2003, Mummert et al. 2003), which can readily ingest contaminants adsorbed to sediment particles while feeding (Newton 2003), and on the glochidia, which appear to be very sensitive to toxins (Goudreau et al. 1993, Jacobson et al. 1997). Mussels are very intolerant of heavy metals (Keller and Zam 1991, Havlik and Marking 1987), and even at low levels, certain heavy metals may inhibit glochidial attachment to fish hosts (Huebner and Pynnönen 1992). Cadmium appears to be the heavy metal most toxic to mussels (Havlik and Marking 1987), although chromium, copper, mercury, and zinc also negatively affect biological processes (Wilcove and Bean 1994; Naimo 1995; Keller and Zam 1991; Jacobson et al. 1993, 1997; Keller and Lydy 1997).*
>
> *Among pollutants, ammonia warrants priority attention for its effects on mussels (Augspurger et al. 2003), and has been shown to be lethal at concentrations of 5.0 parts per million (ppm) (Havlik and Marking 1987). The un-ionized form of ammonia (NH_3) is usually attributed as being the most toxic to aquatic organisms (Mummert et al. 2003), although the ammonium ion form (NH_4^+) may contribute to toxicity under certain conditions (Newton 2003). Documented toxic effects on marine and freshwater mussels include reduction in time valves are held open for respiration and feeding; impaired secretion of the byssal thread; reduced ciliary action impairing feeding; depleted lipid, glycogen, and other carbohydrate stores; altered metabolism; and acute toxicity (Goodreau et al. 1993, Mummert et al. 2003). Sources of ammonia are agricultural (e.g., animal feedlots, nitrogenous fertilizers), municipal (e.g., effluents of out-dated WWTPs), and industrial (e.g., waste products) as well as from precipitation and natural processes (e.g., decomposition of organic nitrogen) (Goodreau et al. 1993, Hickey and Martin 1999, Augspurger et al. 2003, Newton 2003). Atmospheric deposition is one of the most rapidly growing sources of anthropogenic nitrogen entering aquatic ecosystems (Newton 2003) and livestock are the largest global source of atmospheric ammonia (Robarge et al. 2002). Agricultural sources of ammonia may be highly variable over time (Hickey and Martin 1999), compounding the determination of accurate concentration readings.*
>
> *Toxic effects of ammonia are more pronounced at higher pH and water temperature because the level of the un-ionized form increases as a percentage of total ammonia (Mummert et al. 2003, Newton 2003). Therefore, this contaminant may become more problematic for juvenile mussels during low flow, high temperature periods (Newton et al. 2003). In stream systems, ammonia is frequently at its highest concentrations in interstitial spaces where juvenile mussels live and feed (Whiteman et al. 1996, Hickey and Martin 1999, Augspurger et al. 2003), and may occur at levels that exceed water quality*

standards (Frazier et al. 1996). Due to its high level of toxicity and the fact that the highest concentrations occur in the microhabitat where mussels live, ammonia should be considered among the factors potentially limiting survival and recovery of mussels at some locations (Augspurger et al. 2003).

Pesticide residues from agricultural, residential, or silvicultural activities commonly end up in streams where the effects (based on studies with laboratory tested mussels) may be particularly profound (Fuller 1974, pp. 215-273). Factors such as persistence in the environment, metabolism, interaction with other substances, physiologic variations such as those associated with age, environmental temperature, nutritional status, and other factors can affect the toxicity of pesticides (Zinkl *et al*. 1991, pp. 234-255). However, there is currently no available information on the sensitivity of this species to common pesticides. Nonetheless, chemical run-off or spills have resulted in mussel mortalities in various regions of the country (Fleming *et al*. 1995, pp. 877-879), and we believe that the rabbitsfoot would be similarly susceptible to pesticide residues.

The low pH commonly associated with metal mine runoff can reduce glochidial encystment rates (Huebner and Pynnönen 1992, pp. 2348-2355). Acid mine runoff may thus impact mussel recruitment. Sedimentation runoff from mines may clog interstitial spaces (Branson and Batch 1972, pp. 507-518), habitat critical for juvenile mussels. A recent study by Kansas Department of Health and Environment documented strong negative correlation between the distribution and abundance of native mussels, including rabbitsfoot, and sediment concentrations of lead, zinc and cadmium in the Spring River system (Angelo et al. 2007, pp. 477-493). Specific threats to each extant stream population are discussed in more detail below.

Lower Great Lakes Sub-basin

The Great Lakes Basin represents the most zoogeographically distinct population center for the rabbitsfoot. The Fish Creek watershed, which drains into the St. Joseph River and then Maummee River, is mostly in agriculture and susceptible to sedimentation, nutrification, pesticides, and other potential contaminants (Watters 1988, pp 1-2; Sparks et al. 1999, pp. 12-13). There have been two documented mussel kills in Fish Creek (circa 1988), one suspected from manure runoff from a hog farm and the other from a diesel spill that impacted the lower reach. Upstream land use and nonpoint source impacts may still impact the lowermost habitat and the rabbitsfoot (i.e., the swampy area is not a 100 percent sink of nutrients, sedimentation, other toxicants). The channel is actively incising without lateral migration (T. Crail 2009 pers. comm.). Due to the sporadic and restricted distribution, low abundance, and little if any recruitment, this population is highly susceptible to the aforementioned stressors resulting from agriculture and stochastic events.

Ohio River System

The best extant population of the rabbitsfoot in the Ohio main stem exists below the two wicket dams (Lock & Dams 52 and 53) where the Ohio retains more typical riverine habitat than below the high-level dams upstream. Construction on the high-level Olmsted Lock & Dam (to replace Lock & Dams 52 and 53) is expected to be complete in 2014 (M. Turner 2008 pers. comm.) and may impact rabbitsfoot habitat in the lower Ohio River. Olmsted Lock & Dam, located at river mile 964.4, will operate similar to the older structures (wicket dam with barges navigating over the dam at high water or approximately 60% of the year) and is designed to back water up to Smithland Lock & Dam during low flow periods. Lock & Dams 52 and 53 are slated for removal. Most of the remaining free-flowing riverine habitat in the lower Ohio will be compromised at least seasonally.

In general, linear miles of mussel beds in the Ohio River decreased over 20% from 1967 to 1982, believed to be from activities associated with navigation (e.g., maintenance dredging, fleeting areas, loading/unloading facilities, bottom instability from propeller wash turbulence) (Williams and Schuster 1989, pp. 7-10). Siemsen (1993, p. 106) estimated that as much as two million cubic yards of material was removed annually from the lowermost Ohio River navigation channel from Smithland Lock & Dam (river mile 918) downstream to the mouth (river mile 981). Other changes were noted by Clarke (1995, p. 72), who also observed that sand and gravel mining was taking place in the immediate vicinity of the rabbitsfoot he collected in 1994. Sand and gravel mining and channel maintenance activities continue to increase channel instability and sedimentation in the Ohio River, which threatens the rabbitsfoot population. Threats to mussel populations are the same as those impacting all freshwater riverine species (e.g., siltation, chemical pollution, impoundment, instream disturbances and competition from exotic species) and have reduced the lower Ohio River fauna adjacent to Illinois by 40% since 1969 (Cummings and Mayer 1997, pp. 130 and 142).

Similar to the Ohio River, nine locks and dams were constructed on the lower Allegheny River, a tributary of the Ohio River, over a 72 river mile reach from Armstrong County to Pittsburgh that disrupted extensive historical riverine habitat for the rabbitsfoot. The construction of Kinzua Dam on the upper main stem (forming Allegheny Reservoir) may also have destroyed rabbitsfoot habitat in extreme northwestern Pennsylvania. Current threats to the rabbitsfoot in the Allegheny River include ongoing channel maintenance activities, sedimentation, and silvicultural activities (R.M. Anderson 2009, pers. comm.).

Although many streams in western Pennsylvania have improved water quality since the early 1900s, water quality issues remain with 1,018 rivers, streams, and creeks impaired in 1997-1998 (i.e, sediments [41%], agriculture [27%], metals [41%], nutrients [20%], unknown [11%] and dissolved oxygen/organic enrichment [10%]; http://www.scorecard.org/env-releases/water/cwa-state.tcl?fips_state_code=42#cause). Oil and gas extraction is accelerating in the watershed, and a large refinery near the river in Warren is a potential source for pollutants. Additionally, natural gas development in the Marcellus Shale formation presents imminent metal, hydrocarbon, and sediment contaminant issues as 1,000s of wells are being or will be drilled during the 20-40 year life span of this activity (R.M. Anderson 2009, pers. comm.). Coal mining activities historically occurred in western Pennsylvania and as coal prices increase, this activity again will become a threat to the rabbitsfoot in the Allegheny River.

Threats to the rabbitsfoot in French Creek, a tributary to the Allegheny River, include nutrients from agriculture, aging septic systems (R.M. Anderson 2009, pers. comm.), sedimentation, and municipal runoff and effluents. Pennsylvania is encouraging residents to get off septic systems and several small towns in the watershed will soon have new concentrated point source municipal discharges. Oil and gas development poses the same threats to rabbitsfoot in this watershed as described above in the Allegheny River (R.M. Anderson 2009, pers. comm.) and projections call for increases in these activities given our domestic energy policy. LeBoeuf and Conneautee creeks are both tributaries to French Creek and have similar threats.

Although most of the lower main stem of Muddy Creek, a tributary of French Creek, occurs on Erie National Wildlife Refuge (NWR) lands, the population is threatened by sedimentation, agricultural runoff, and developmental pressures on non-refuge lands in the watershed (Butler 2005, p. 34). Three live rabbitsfoot specimens were found at 3 sites during a Service survey of 20 sites in 2003 (P. Morrison, Service, pers. comm., 2005). The three sites were in a two river mile reach and located about four miles above the mouth.

In the early 1990s, habitat in the Walhonding River, a tributary of the Ohio River, was good and the stream supported 33 of 38 populations of historical mussel species of occurrence (Hoggarth 1995-96, p. 163). More recent evidence from a couple of sites sampled during 2006 suggests that habitat quality in the river has declined markedly. One of Hoggarth's best sites was choked with filamentous algae and only a few live mussels were found (B. Butler 2008, pers. comm.). Threats were summarized by Hoggarth (1995-96, p. 150), but the apparent decline in habitat quality is likely on the verge of extirpating the rabbitsfoot from this river. An impoundment on the Walhonding River, Mohawk Dam (~RM 17.5), was built on the main stem in 1936 and operates as a "dry dam" to temporarily control flood waters. The dam is not nearly as destructive as a permanent reservoir, as indicated by the presence of live rabbitsfoot both upstream and downstream of the structure. Developmental and agricultural pressure occurs, particularly upstream of Mohawk Dam. Malacologists conducting mussel surveys in August, 2008, reported the Tuscarawas River color as "dark tea stained" similar to effluent discharged from a paper plant (tannins). They were unable to track the source upstream, but malacologists working many miles downstream in the Muskingum River (the Tuscarawas and Walhonding rivers converge to form the Muskingum River) reported similar conditions on the same day suggesting that a considerable effluent discharge had impacted many river miles (S. Ahlstedt 2009, pers. comm.).

Threats to Killbuck Creek, a tributary to Walhonding River, include a heavy sediment load resulting from agricultural practices in the watershed (S. Ahlstedt 2009, pers. comm.).

Threats to the Muskingum River, a tributary of the Ohio River, include cumulative effects from sources mentioned above in the Walhonding River and Killbuck Creek. The continued operation of the Dresden gas-fired power plant water intake and periodic dredging requirements to maintain the water intake structure threaten the only known extant rabbitsfoot locality in the Muskingum River (EAA 2009, p. 3).

Threats to Big and Little Darby creeks, tributaries of the Ohio River, include developmental activities associated with metropolitan Columbus (e.g., suburban subdivisions and associated development), agricultural runoff, and sedimentation. Localized sand and gravel mining and heavy metal pollutants are also documented in Big Darby Creek (Watters 1994, pp. 104-105). Watters (1990 pp. 7 and 17) noted agricultural runoff particularly from cattle access to Little Darby Creek (prevalent in the rabbitsfoot reach), and sedimentation. He referred to a stream reach below West Jefferson (and just below the extant rabbitsfoot reach) as a “dead zone” due to the lack of L/FD mussel species. Two point-source discharges, including a municipal wastewater treatment plant (WWTP), occur downstream of West Jefferson in Little Darby Creek and may be the primary impact in this severely diminished reach. A lowhead dam at the mouth of Little Darby was removed in 1990, thus restoring free-flowing status to the lower main stem and removing a potential barrier to mussel and host fish movements (Watters 1990, p. 17). However, there has been no apparent improvement of rabbitsfoot (B. Butler 2008, pers. comm.).

The South Fork Kentucky River, a tributary of the Ohio River, population is threatened by coal mining, sedimentation, straight piping of untreated domestic effluents, municipal wastewater, and runoff of various other pollutants in the steep terrain characteristic of this Cumberland Plateau watershed (R.R. Cicerello 2004, pers. comm.).

A series of six lock and dams was constructed on the lower half of the Green River, a tributary of the Ohio River, decades ago and extend upstream to the western boundary of Mammoth Cave National Park (MCNP). Only the lower-most two are operational, and one of the four others has been breached. The upper two lock and dams probably destroyed rabbitsfoot habitat, particularly Lock and Dam 6, which flooded the central and western portions of MCNP. Approximately 30 RMs of main stem habitat was also eliminated with the closure of Green River Reservoir Dam (GRRD) in 1969. Releases from GRRD have altered flows and temperature regimes and caused bank slumping in the dam’s tailwaters. Additional threats to this rabbitsfoot population include low water fords (erosion and sedimentation, altered habitat), nonpoint source pollutants (sediment, nutrients), oil and gas development, 12 point source dischargers, and altered hydrology associated with dams (Kentucky State Nature Preserves Commission and The Nature Conservancy 1998, pp. 15-19). Several hazardous material spills (unspecified chemical pollutants) have been documented in recent decades and the potential for additional spills still exists based on historical occurrences and lack of measures to prevent future spills. Nonpoint source pollutants such as sedimentation, pesticides, and fertilizers have also impacted the system. Agricultural practices include cattle trampling stream banks and contributing to excessive nutrification of stream segments, row cropping in riparian areas, and general removal of riparian vegetation. Oil and gas development in the late 1950s polluted the Green River with chlorides, metals, and dissolved solids. Although a historical threat, the potential for new threats (i.e., sedimentation, increased chlorides, and other pollutant associated with the industry) from a renewed interest in oil and gas development continue to exist. Recent oil and gas development activities have been noted immediately upstream of MCNP and poses a current threat of oil, processing chemical, and byproduct spills. A dozen point source discharges are permitted in the upper Green River between GRRD and MCNP. Pollutants from these discharges include silt, nutrients, ammonia, chlorine, chloramines, and other toxic compounds.

Threats to the Barren River, a tributary of the Green River, include sedimentation, agricultural practices, and general developmental activities (Butler 2005, p. 43). A significant portion of the free-flowing Barren was lost when Lock & Dam 1 and Barren River Reservoir were constructed. Flow releases from the reservoir continue to threaten the rabbitsfoot last collected approximately 10 river miles downstream.

Gordon (1991, pp. 4-5) noted that the Rough River, a tributary of the Green River, was “exceedingly turbid” and large sections of the river had “thick deposits of hard mud,” purportedly due in part to coal strip mining activity that occurred decades ago. The potential for new threats from coal strip mining in the watershed exists given the recent increases in coal prices. These conditions may also be attributable to the lowermost two-thirds of the river below Rough River Dam having had “channel improvements” conducted in the past to ostensibly improve flows and reduce flood damage (Corps 1979, map). The dam destroyed or altered riverine habitat in about a third of the upper Rough River main stem. These are the primary threats that ultimately led to the rabbitsfoot demise and potential extirpation. Other threats include sedimentation, agricultural practices, and possibly deleterious flow releases from the dam.

Threats in the Eel River, a tributary of the Wabash River, system also include agricultural runoff and sedimentation impacts. Several mill dams also occur on the Eel, some in various states of disrepair. These mill dams have (1) altered the rivers hydrologic function, (2) decreased habitat availability and quality, (3) increased sediment deposition upstream, (4) act as nutrient sinks in upstream areas affected by sedimentation, (5) lower dissolved oxygen concentrations, (6) lead to greater fluctuations in water temperature, and (7) block fish passage, all of which have an adverse impact on rabbitsfoot (B.E. Fisher 2009, pers. comm.).

Threats to the rabbitsfoot in the Tippecanoe River, a tributary of the Wabash River, were noted by Cummings and Berlocher (1990, pp. 88-90) and Ecological Specialists, Inc ([ESI] 1993, pp. 89-92). They include evidence of nutrient enrichment manifest in abundance of filamentous algae in some reaches, particularly associated with point source discharges near Warsaw, Indiana. Sedimentation and nutrients increase in downstream areas due to stream bank erosion resulting from insufficient riparian buffers, unrestricted livestock access, and channel modification in tributaries and along the main stem, all of which have resulted in reduced fish and mussel abundance and richness. The extent of suitable habitat in the lower river also has been compromised by two major reservoirs, Shafer and Freeman. Riffle habitats are impacted by tailwater conditions, such as temporary exposure during low flow releases. The rabbitsfoot is no longer found in the tailwaters of the lower Tippecanoe due to fluctuations in water levels below the dams. As previously stated, this species is particularly vulnerable to predation and water fluctuations due to the seasonal movement patterns associated with its brooding behavior.

Coal strip mining historically occurred in the Salt Fork and Middle Fork Vermilion drainages. The rabbitsfoot has not been found live in these two streams since the 1920s and is considered extirpated (Cummings et al. 1998, p. 95). Water quality is considered very well in the North Fork Vermilion, a tributary of the Wabash River, drainage. Cummings et al. (1998, p. 97) summarized current threats to the mussel fauna in this primarily agricultural watershed. These include runoff from crop lands and other agricultural activities (due to the restricted riparian zone incapable of acting as a buffer from these upland activities), poorly treated wastewater discharges, and channelization of some headwater streams. The Middle Branch North Fork Vermilion River population is very small and apparently contiguous with the rabbitsfoot occurring in the main stem North Fork, thus representing an upstream extension of this population.

Cumberland River System

The East Fork Stones River, a tributary of the Cumberland River, population was severely impacted by the construction of J. Percy Priest Dam on the lower main stem in 1968 which destroyed approximately 45 miles of stream, including known rabbitsfoot sites, and isolated the two forks. Dam construction contributed to the extirpation of the rabbitsfoot from the West Fork (last found live in mid-1960s). Chemical data collected during the 1980-81 mussel survey work indicated declining water quality in the system (Schmidt et al. 1989, p. 57). Two small mill dams disrupt habitat in the lower East Fork (Corps, no date). Other threats in this mostly rural but rapidly developing watershed include sedimentation, agricultural runoff, over-enrichment, effluent discharges, instream gravel mining, destabilized streambeds, reduction in habitat from channels scoured to bedrock, and developmental activities (i.e., altered hydrologic regime associated with increases in impervious surfaces, nutrient runoff, pesticides, etc; Hatcher and Ahlstedt 1982, p. 6; Schmidt et al. 1989, p. 57; Ahlstedt 2002, p. 8). The rabbitsfoot in the Red River is threatened primarily by agricultural practices that lead to increased sedimentation and nutrient runoff.

Tennessee River System

Nearly the entire length of the 650-mile long Tennessee River main stem has been impounded destroying hundreds of miles of riverine habitat for the rabbitsfoot. The main stem is currently maintained as a navigational channel. Thus maintenance activities and impacts associated with barge traffic are continued threats. For instance, the widening of the locks at Kentucky Dam is near completion. A plan to deepen the navigation channel has been proposed (D.W. Hubbs 2009, pers. comm.). These activities if approved and funded, would alter habitat by increasing substrate disturbance and sedimentation associated with channel maintenance operations (i.e., dredging and snag removal) and altered flow regimes. Gravel mining activities also occur in the lower Tennessee River in Tennessee. Severe bank erosion is ongoing along some reaches of the river below Pickwick Landing Dam, with some sites losing several feet a year (D.W. Hubbs 2010, pers. comm.). Poorly maintained buffers and navigation activities exacerbate this problem.

The Paint Rock River, a tributary of the Tennessee River, drainage has been severely affected in past decades by impoundments, stream channelization, erosion, and agricultural runoff (Fobian et al. 2008, pp. 3-4; Alhstedt 1995-1996, pp. 74-79). Construction of Wheeler Dam began in 1933 and was completed in 1936 forming Wheeler Reservoir. Another major influence on rabbitsfoot populations was the channelization and removal of snags and riverbank timber in the upper Paint Rock River and the lower reaches of Larkin Fork, Estill Fork and Hurricane Creek, by the U.S. Army Corps of Engineers during the 1960s. This direct headwater habitat manipulation was probably a large contributor to freshwater mussel loss in the basin. Continued threats to the watershed include siltation and erosion due primarily to poor farming practices along with commercial and residential development. Specific practices that increase siltation and erosion include clearing of riparian vegetation, cattle access/grazing, timber clear cutting, head cutting, gravel mining, in stream ATV traffic, and runoff from poor farming and construction actions. Nonpoint source agricultural runoff and chemical spills are also a threat (Fobian et al. 2008, pp. 3-4).

Impoundments have played a huge role in the demise of the mussel fauna of the Elk River, a tributary of the Tennessee River. The rabbitsfoot is unable to survive in impounded areas due to sedimentation and loss of host fish necessary to complete its life cycle. Three large reservoirs (one in Alabama and two in the Tennessee headwaters) have flooded about 80 miles of the main stem (~40% of its length). Foremost among current threats are flow releases from Tim’s Ford Dam (TFD), which started operating in 1970. Hydropeaking (releases during peak electricity generating times) and hypolimnetic discharges (cold water released from the bottom of deep reservoirs) historically contributed to highly variable daily flow rates, severe bank sloughing, rabbitsfoot recruitment failure due to movement patterns associated with its reproductive behavior and loss of fish host, and habitat conditions unsuitable for most riverine mussels (i.e., severe water fluctuations, habitat instability, lower dissolved oxygen and water temperature, etc; Service 1999 pp. 6-7; Hubbs 2002, p. 3). Dam discharge conditions historically were not conducive for most mussel species in the lower river due to factors previously mentioned, where population numbers remain low. TVA has entered into an agreement with the Service to alter releases from Tims Ford Dam to reduce the severity of flow fluctuations and increase temperatures beginning approximately 13 miles downstream of the dam (D.W. Hubbs, TWRA2009, pers. comm.). Flow conditions below TFD made the Elk a classic example of the potential effects of tailwater discharges on the mussel fauna, particularly the rabbitsfoot. Recent (2006) consultation between the Service and TVA has resulted in operational changes at TFD that should warm water releases and lessen water fluctuations, which should eventually restore approximately 30 miles of habitat and minimize this threat (S. Chance, Service 2008, pers. comm.). Altered flow releases by TVA's operation of Tim's Ford Dam on the Elk River have not yet demonstrated their benefit to mussel populations inhabiting the river (D. Hubbs, TWRA 2010, pers. comm.).Other negative factors include instream gravel mining, agricultural runoff, and sedimentation impacts (Ahlstedt 1983, pp. 43-50; Service 1999, pp. 6-7).

McGregor and Garner (2004, p. 61) briefly summarized the threats in Bear Creek, a tributary of the Tennessee River. Pickwick Landing Dam on the Tennessee River main stem impounds 20 miles of the lowermost section of Bear Creek. Four flood-control reservoirs were constructed in the system between 1969 and 1979 (Phillips and Johnston 2004, p. 206), inundating about 50 miles of suitable mussel habitat. Tailwater reaches below the impoundments have experienced destabilized stream banks and resultant sedimentation impacts to the channel from rapid releases of stored water. Riparian buffers are lacking in some stream reaches further exacerbating erosion and sedimentation. Strip mining has also impacted the system by increasing sedimentation. Other threats include channelization and stream diversions, silvicultural practices, eutrophication, and erosion from crop fields and other agricultural lands.

Despite the current health of the rabbitsfoot population, there are some pervasive threats in the Duck River, a tributary of the Tennessee River, system. Summarized by TNC (2003, Priority Threats Section – no page numbers), they include habitat disturbance, destruction, or fragmentation; modifications in natural flow regimes, particularly water withdrawals from developmental activities; and nutrient, contaminant, and sediment loading. The sources of these threats can be summarized as pressures from rapidly growing and urbanizing communities and historical and continuing incompatible agricultural practices. Pressures from growing communities include commercial and industrial development, primary home development, and increases in impervious surfaces. Agricultural impacts include cattle access to streams, loss of riparian areas, stream bank cropping, small scale channelization projects, and livestock lots. Three lowhead dams at Shelbyville (RM 221), Lillards Mill (RM 179), and Columbia (RM 132), have physically fragmented rabbitsfoot populations in the Duck River for decades. The rabbitsfoot population in the Duck River occurs from river mile 37 upstream to river mile 207, but the species is most abundant in the reach from river mile 179 downstream to river mile 130 (basically upstream of Old Columbia Dam pool to Lillards Mill Dam). The species is sporadic elsewhere in the river. There is the possibility that host fish passage occurs during floods, but genetic interchange within the larger rabbitsfoot population in the Duck may be unlikely without human intervention.

In the Duck River, recent research has demonstrated that an identifiable pattern of dry hydrographs and an order of magnitude higher wet hydrographs of rivers in the southeastern United States alternate in approximate 30-year cycles in synchrony with the Atlantic Multidecadal Oscillation (AMO). Predictions based on the AMO indicate that for the short term (2-4 years), discharge in the Duck River will be below normal. Thus, a water shortage in the Duck River basin is likely in the short-term. A water shortage in the basin is inevitable in the long-term because of increased demand for water fueled by population growth in the watershed and exacerbated by climate change resulting in continued water conflicts. The water shortage experienced during the 2007 – 2008 drought pales in comparison to what may occur in the future (Chance and Layzer 2009, SSP Proposal). A number of surface water withdrawal proposals on the Duck River, particularly in the Columbia and Shelbyville areas, from industrial, municipal, and commercial sources associated with increases development in the watershed threaten to exacerbate drought conditions during seasonal low flows.

Lower Mississippi River Sub-basin

Threats and management recommendations in the St. Francis River, a tributary of the Mississippi River, system were detailed by Hutson and Barnhart (2004, pp. 86-88). The existing population of rabbitsfoot is located upstream of Wappapello Reservoir, which inundates approximately 30 RMs of the upper St. Francis. Past metals mining and smelting (until the 1940s) has resulted in continuing heavy metal (e.g., lead, iron, nickel, copper, cobalt, zinc, cadmium, chromium) contamination of surface waters in the area upstream of the rabbitsfoot reach. Metals mining and smelting remain a constant source of heavy metal (e.g., lead, iron, mickel, copper, cobalt, zinc, cadmium, chromium, and silver) contamination of surface waters and sediments in the St. Francis River basin since the early eighteenth century. Recent and historic metals mining and smelting have produced enormous volumes of contaminated wastes that are a continuing threat to this species. Most of these mining wastes are stored behind poorly constructed dams and impoundments (A. Roberts 2008, pers. comm,). The headwaters of Wappapello Reservoir and the confluence with Big Creek (with habitat degradation primarily from mining activities) may effectively limit the downstream distribution of the rabbitsfoot in the St. Francis. The short river reach that has supported the rabbitsfoot population over the past three decades is subject to sedimentation and agricultural practices. Below the dam, the river enters the Mississippi Embayment, where it has been drastically altered by channelization, construction of levees, diversion ditches, control structures, floodways (Bates and Dennis 1983, p. 14), and otherwise impacted by intensive agricultural practices (i.e., row crops; Hutson and Barnhart 2004, pp. 86-88).

The continued survival of the rabbitsfoot, along with one of the densest populations of mussels in North America, is imminently threatened by a Corps “flood control” project on the Big Sunflower River, a tributary of the Mississippi River. The first maintenance item included 7.2 miles of clearing and snagging on the Little Sunflower River and was completed in August 2000. The project was scheduled for completion in June 2008. However, the Corps prepared a Supplemental Environmental Impact Statement (SEIS) to update the environmental documentation that was scheduled for release in November 2007. Mississippi Department of Environmental denied water quality certification permit(s) for the project, thus the proposed project cannot move forward at this time. It is currently unclear whether this project will be completed, but it remains a Corps priority and as such an imminent threat. This planned project prompted American Rivers, a non-governmental organization, in 2003 to rank the Sunflower as the most endangered river in America (Mississippi Interstate Cooperative Resource Association [MICRA] 2003a, pp. 5-6). Dredging for this project, if implemented, is planned to take place downstream of Indianola, but head-cutting may ultimately destabilize the substrate where the rabbitsfoot now exists. Additional impacts in the Big Sunflower include agricultural runoff and sedimentation from intensive row-crop farming, and pumping groundwater for irrigation, which is lowering the water table and decreasing flow rates in the river.

The survival of the rabbitsfoot in the Big Black River, a tributary of the Mississippi River, is threatened by agricultural runoff (i.e, pesticides), sedimentation, and occasional point source discharges (Hartfield and Rummel 1985, p. 117).

White River System

Impoundments have played a major role in the rabbitsfoot’s demise in the upper portion of the White River, a tributary of the Mississippi River, most of which is now impounded or otherwise impacted by cold tailwaters. The Corps maintains the lower 260 river miles as a navigation channel for barge traffic. This section of river (essentially from the confluence of the Black River downstream) is currently impacted by channel training devices and commercial navigation activities. Corps plans include further channel modification to improve navigation in the system by constructing hundreds of wing dikes in the navigation channel. In 2008, there was a congressional omnibus bill to authorize the Corps to increase the navigation channel upstream from Newport, Arkansas to Batesville, Arkansas. This project would have eliminated the last shoals from the lower White River further threatening the rabbitsfoot population, but the project was eventually deleted from the bill. Navigation related projects on the White River are a continual threat to the rabbitsfoot population, but are ultimately dependent upon congressional support and appropriations that are not present at this time. Work has begun on the Grand Prairie Irrigation Project that would annually divert more than 100 billion gallons of water from the White River. These projects prompted American Rivers to label it the fifth most endangered river in America in 2002 (MICRA 2002a, p. 9). While impacts to the rabbitsfoot from this project are expected to be minimal, it is difficult to project what the long-term effects of removing this quantity of water will have on the river and the associated mussel populations. Other threats to the rabbitsfoot in the White River include gravel mining (summarized by Harris 1997, p. 1), sedimentation, and pollutants.

Threats to War Eagle Creek, a tributary of the White River, include runoff from poultry production, other agricultural runoff, and sedimentation from eroding stream banks and unpaved roads in the watershed. Gravel mining is prevalent in the watershed further exacerbating sedimentation and instream channel alteration. Unrestricted cattle access and lack of riparian buffers has lead to numerous stream banks destabilizing, thus increasing channel instability.

Despite its current designation as the Buffalo National River, a tributary of the White River, in the NPS system, the river is not without its problems. Pollutants from resort subdivisions and related developmental activities outside the park boundaries, nonpoint source pollutants such as sediment and nutrients associated with various land use activities, and altered stream geomorphology from clearing of riparian areas for conversion of forested areas to pasture threaten the Buffalo population of the rabbitsfoot (C. Davidson, 2009, pers. comm.).

Hutson and Barnhart (2004, pp. 155-156) detailed threats in the Black River, a tributary of the White River, in Missouri (where the rabbitsfoot is extirpated). Landuse in the lower portion of the watershed in Arkansas is primarily agricultural. Many streams have been channelized and ditches now comprise significant portions of the watershed. Sedimentation, pesticide, and fertilizer runoff from these croplands potentially affect the rabbitsfoot population in the lower Black River (Arkansas portion). Municipal runoff is a lesser concern but may also affect water quality in the river. The lower Current River, a tributary to the Black River, appears to have a large sediment load from eroding stream banks and erosion from row crop fields in the watershed that are reducing rabbitsfoot habitat. Landuse is primarily cropland, leading to sedimentation, pesticide, and fertilizer runoff impacts in the Current River.

The rabbitsfoot is threatened in the lower Spring River, a tributary of the Black River, by developmental activities primarily associated with retirement villages, recreation, sedimentation, and agricultural runoff. Threats in the South Fork Spring River include a very unstable stream channel, thought to be the result of low water road crossings with culverts (which act as lowhead dams), blowing out areas downstream from accelerated flow rates through the culverts (C. Davidson 2009, pers. comm.). Cattle having easy access to stream banks have exacerbated sedimentation in the stream and contribute nitrogenous wastes that impact this rabbitsfoot population.

The Strawberry River, a tributary of the Black River watershed, is primarily composed of forests and agricultural lands, primarily cattle production. Increased sedimentation followed by nutrification is the primary stress to this population. Sources of sedimentation were determined to be incompatible agricultural practices, road maintenance activities, and riparian conversion. Unpaved roads contribute the greatest amount of sediment to the river, especially from tributaries such as North Big Creek. Lesser threats include gravel mining and construction activities.

Davidson and Wine (2004, pp. 2-4) conducted a stress analysis in the upper Little Red River watershed. Land use patterns in the Middle Fork Little Red River, a tributary of the Little Red River then the White River, watershed are dominated by forest and pasturelands. Davidson and Wine (2004, pp. 15-17) identified dozens of stress points, most of them erosion associated with poorly maintained buffers, sloughing banks, and low-water crossings. Numerous sites were also identified where there was unrestricted cattle access. Cattle in the stream probably accounted for the elevated fecal coliform levels, which typically are associated with increases in nutrients associated with cattle defecating in the stream, at the best rabbitsfoot site (R. Winterringer 2005, pers. comm.). Lack of riparian buffers and signs of bank failure along the stream indicated that sedimentation may become an increasing problem in the future at this site (R. Winterringer 2005, pers. comm.). Natural gas exploration and development is a newly-emerging threat to rabbitsfoot populations in the Middle Fork Little Red River. Significant erosion and sedimentation issues associated with natural gas development activities, particularly pipelines, was first documented during. The magnitude of the effects to the Middle Fork Little Red River from 2008 - 2009 also was exacerbated due to above average rainfall which led to more frequent and larger pipeline erosion events (C. Davidson, Service 2010, pers. comm.).

Arkansas River System

The Neosho River, a tributary to the Arkansas River, is no longer considered "a splendid clear water stream" as Isely (1924) described it from survey work conducted in 1912. According to Obermeyer et al. (1997a, p. 114), nutrients and sediment loading are considered to be major threats in southeastern Kansas, making the Neosho and other streams perennially turbid. Numerous dams occur in the system, including 16 lowhead and 2 major reservoirs have resulted in decreased species richness (Dean et al. 2002, p. 233). Nearly the entire length of the river in Oklahoma (~200 miles) is now impounded or impacted by tailwater releases from three major dams (Matthews et al. 2005, p. 308). Evidence of head-cutting (e.g., bank scouring, stream banks devoid of perennial vegetation) was noted below John Redmon Dam. Juracek (1999, pp. 3-5) noted bank widening, channel erosion, and channel bar formation below lowhead overflow dams in the lower Neosho in Kansas, resulting in habitats generally unsuitable for mussels. Oil fields, concentrated animal feeding operations, cropland runoff, and stochastic events (e.g., drought) were also considered factors in the decline of the rabbitsfoot (Obermeyer et al. 1997a, pp. 113-115). The Neosho River is also severely impacted by heavy metals from mining activities (A. Roberts 2008, pers. comm.). All these factors continue to threaten the rabbitsfoot population and have lead to an overall decline of the mussel fauna in the Neosho River when compared to Isley's (1924) description of the river in 1912 as "a splendid clear water system".

Juracek (1999, pp. 3-5) reviewed the geomorphic effects of lowhead overflow dams in southeastern Kansas, concluding that the impacts downstream were substantial and manifest in channel widening, channel erosion associated with plunge pools, and formation of unstable gravel bars below dams. All these impacts serve to decrease mussel habitat, with channel widening possibly the most detrimental to the shoreline-dwelling rabbitsfoot.

The Verdigris River, a tributary of Arkansas River, system population has been impacted historically by numerous dams. The basin is primarily in agriculture making sedimentation, nutrients, pesticides, and water withdrawal for irrigation current threats to this population. The population is restricted to three sites downstream of Oologah Lake. Flow releases from the dam threaten the extant population due to seasonal migration to shallower waters when female rabbitsfoot are brooding, thus leaving them vulnerable to desiccation if flows drop rapidly following prolonged periods of higher flow rates.

Contamination by heavy metals (e.g., zinc, lead, cadmium) from mine tailings in the TriState Mining Superfund Site in the Turkey Creek watershed have severely degraded the Spring River, a tributary to the Neosho River, mussel fauna (including the rabbitsfoot) below the confluence (N.L Eckert 2005, pers. comm.), while other threats include nutrient and sediment loading and “pollution and dams” (Obermeyer et al. 1997a). In addition, two major tributaries (Center and Shoal Creeks) have been severely impacted by heavy metals from mining activities (A. Roberts 2008, pers. comm.). Empire Reservoir in Kansas has eliminated several miles of riverine habitat in the Spring River.

Matthews et al. (2005, pp.294 and 321) and (Vaughn 2003, pers. comm.) summarized threats to the mussel fauna, which includes the rabbitsfoot, in the Illinois River system, a tributary to the Arkansas River. Non-point source organic runoff from poultry farming and municipal wastewaters occurs in the watershed, and is most prevalent in Arkansas, which has less strict enforcement than does Oklahoma. The headwaters of the Illinois drain Benton County, Arkansas. With 308 broiler chicken farms, the county is ranked third among the nation’s producers (http://www.dpichicken.org/index.cfm?content=news&subcontent=details&id=184). Phosphorus levels are 10 times higher in the Illinois at the Arkansas border than Oklahoma regulations permit (MICRA 2002b, p. 10). Sedimentation primarily from riparian developmental activities is a concern. Increasing impervious surfaces associated with urban development in northwest Arkansas and clearing of native riparian habitat for conversion to pasture land has led to rapid channel destabilization during the past couple years (C. Davidson 2009, pers. comm.). The Illinois has been designated an Oklahoma Scenic River and it supports a large recreational canoeing and rafting industry. These companies remove log jams and other woody debris, both of which can lead to increased stream instability that may impact rabbitsfoot populations. Most existing mussel beds are now found in backwaters and side channels, not the river’s main channel (C.C. Vaughn 2003, pers. comm.). Two large reservoirs are located on the river. Lake Frances, on the state border and dividing the extant rabbitsfoot population, is partially drained, but its spillway continues to act as a barrier to fish migration. Tenkiller Ferry Dam impounds or has tailwater influence on the lower river impacting nearly one-third of the entire length of the main stem. While there is no pre-dam data available on the mussel fauna in this stream reach, it is reasonable to assume that this portion of the river supported a diverse mussel assemblage, including rabbitsfoot, just as other reaches of the river support.

Red River System

The activities that threaten the rabbitsfoot in the Little River, a tributary of the Red River, include sedimentation, silvicultural activities (particularly in the upper watershed), runoff associated with chicken farming, and gravel mining in the lower watershed (C.C. Vaughn 2009, pers. comm.; Matthews et al. 2005, p. 308). The Little River is impacted by hypolimnetic releases from two Oklahoma reservoirs, Pine Creek on the main stem and Broken Bow on a tributary, the Mountain Fork Little River (which once had a rabbitsfoot population flooded by the dam). Mussel populations, including the rabbitsfoot, in the reaches of the Little River influenced by the two upstream hypolimnetic reservoir releases are extremely depleted (Vaughn and Taylor 1999, pp. 915 and 917). Additional reservoir construction in this watershed has been proposed and could be detrimental to the remaining rabbitsfoot population, but it is unclear at this time whether additional reservoirs will be permitted and constructed (Galbraith et al. 2008, p. 49). Galbraith et al. (2008, pp. 48-49) reported a massive die-off (> 160 rabbitsfoot specimens) at Site D (one of three long-term monitoring sites in Oklahoma with rabbitsfoot present). The reason for the die-off is unknown, but was species specific. They speculate that the 2005 Oklahoma drought coupled with high water temperature and extensive blooms of filamentous algae may have resulted in extreme physiological stress at this site while low water levels may have increased predation. A third large reservoir created by Millwood Dam negatively influences about 50 river miles of the lower Little River in Arkansas. The rabbitsfoot population is stable in the relatively warmer reach between these tailwater influences and in Arkansas between the Arkansas/Oklahoma state line and Millwood Lake.

Threats to the Glover River, a tributary of the Little River, include sedimentation from logging and gravel mining (Vaughn 2003, pp. 4-5). The fact that most of the upper watershed is now being managed by the U.S. Forest Service rather than private companies may reduce sedimentation from those areas. Gravel mining occurs just 100 feet downstream of the lower rabbitsfoot site. The stream appears highly degraded from the Highway 3 crossing downstream (C.C. Vaughn 2009, pers. comm.). This stretch of degraded habitat may effectively isolate this population from the one in the Little River beginning approximately 10 river miles downstream.

Very little is known about the rabbitsfoot population in the Cossatot River, a tributary of the Little River, and the same could be said about the threats. Millwood Dam negatively influences the lowermost several river miles of the Cossatot and isolates its population from that of the Little River. Gillham Dam is located in the middle reach of the river and its operation influences the section known to have the recruiting population in 1970.

Approximately 100 miles of the upper Ouachita River, a tributary of the Red River, are impounded or influenced by 3 main stem dams. Since the rabbitsfoot is known from both upstream and downstream of this highly degraded river reach, it can be assumed that populations were lost due to impounding of the river. The lower portion of the Ouachita is maintained as an inland waterway by the Corps. A navigation channel is maintained upstream from Louisiana to Camden, Ouachita County, Arkansas. Two locks and dams are located on the river in Arkansas. Camden basically coincides with the downstream-most record for the species in Arkansas. Natural gas and oil development is prevalent in the system and these fuels are transported down the river by barge. In 1995, a barge struck a submerged structure in the Ouachita River below Felsenthal Lock and Dam spilling thousands of gallons of oil into the river, but no rabbitsfoot populations were impacted by this incident. However, the threat of additional spills, while low, is still possible. Other threats in the watershed include bauxite and barium sulfate mining activities, sedimentation, and agricultural activities.

The Little Missouri, a tributary of the Ouachita River, is probably contiguous with that of the Ouachita River forming a single metapopulation centered in and dependent upon the population in the latter river. Forest and pasture dominate the landscape in the lower portion of the watershed. Riparian zones with cattle may result in nutrient loadings and localized stream bank erosion.

Davidson and Clem (2002, pp. 1-2) summarized land use patterns and threats to the mussel fauna (including the rabbitsfoot) of the Saline River, a tributary of the Ouachita River. Approximately 70% of the watershed is comprised of timberlands making silvicultural activities a potential threat where adequate buffers, particularly adjacent to ephemeral and intermittent tributaries, are not protected. About 14% of the land use is in agriculture. Sixteen waste water treatment plants occur in the Saline River watershed and an additional 33 facilities have NPDES permits issued by the State. Another potential threat is from open pit bauxite mines. Once thought to be the sole source of bauxite in the world, the Hurricane Creek watershed, a major tributary to the Saline River, was extensively mined for 100 years until 1990. While reclamation is ongoing to restore the areas mined, acid runoff is still impacting water quality in Hurricane Creek. "Snag and drag" operations to remove tree jams have been planned, but permits were denied. While not an imminent threat, the potential for someone to seek permits to conduct such activities still exists. If permitted, this activity would decimate mussel beds in the lower Saline River, some of which contain rabbitsfoot. The lowermost 12 river miles of the Saline are impounded by a lock and dam on the Ouachita River. No historical data is present to determine whether this portion of river was inhabited by rabbitsfoot, but it is reasonable to assume that it was since rabbitsfoot occupies portions of the river immediately upstream of this reach.

Agriculture is widespread in the Bayou Bartholomew watershed, a tributary of the Ouachita River, and sedimentation is prevalent in the river as a result of this land use (J.A. Brooks 2005, pers. comm.). Water withdrawal for irrigation is also a major concern as landowners often pump significant quantities of water from the stream often leaving mussels, including the rabbitsfoot, exposed to desiccation.

Emerging Threats Range Wide

Water quality, sediment quality, health of host fish and diet all have the potential to influence survival of rabbitsfoot life stages and subsequent reproduction and recruitment. Cope et al. (2008) evaluated what is currently known about contaminant exposure route, exposure location, exposure duration, and relative sensitivity of each life stage. An emerging concern/threat is waterborne (and potentially sediment) toxicant exposure to chemicals that act directly on the neuroendocrine pathways controlling reproduction, which can cause premature release of viable or nonviable glochidia.

Pharmaceutical chemicals used in commonly consumed drugs are increasingly found in surface waters. A recent nation-wide study sampling 139 stream sites in 30 states detected the presence of numerous pharmaceuticals, hormones, and other organic wastewater contaminants downstream from urban development and livestock production areas (Kolpin et al. 2002, pp. 1208-1210). Another study in northwestern Arkansas found pharmaceuticals or other organic wastewater constituents at 16 of 17 sites in seven streams surveyed in 2004 (Galloway et al. 2005, pp. 4-22). As an example of the potential threat to mussels of certain pharmaceuticals, the active ingredient in the commonly prescribed antidepressant Prozac®, according to the manufacturer, is highly toxic to invertebrates and green algae (MICRA 2003b, p. 9). The chemical, which has been found in fish tissues, is claimed to be moderately toxic to fish. The active ingredient in many human prescription anti-depressant drugs belonging to the class of selective serotonin reuptake inhibitors exert reproductive effects on mussels similar to serotonin, making environmental exposures from this class of human pharmaceuticals an imminent threat to native mussel populations (Cope et al. 2008, pp. 454-455).

Watersheds with extant rabbitsfoot populations mentioned above that are currently impacted by wastewater treatment facilities and livestock production are imminently threatened by these contaminants.

In summary, the loss of habitat is a significant threat to the rabbitsfoot. Severe degradation from sedimentation and contaminants threatens the water and habitat quality essential to survival of the rabbitsfoot. Sediment from unpaved roads, natural resource extraction, past and current agriculture practices, silviculture, and construction sites (including modification of stream channels) can cause both lethal and sub-lethal effects to rabbitsfoot populations. Contaminants associated with industrial and municipal effluents (heavy metals, ammonia, chlorine, numerous organic compounds) and agricultural practices may cause decreased oxygen, increased acidity, and other water chemistry changes that are lethal to mussels, particularly the highly sensitive early life stages of mussels. Furthermore, these threats faced by the rabbitsfoot from sources of sedimentation and contaminants are imminent; the result of ongoing projects that are expected to continue indefinitely, therefore, perpetuating these impacts. As a result of the imminence of these threats combined with the vulnerability of the remaining marginal and small populations to extirpation from natural and manmade threats, we have determined that the present or threatened destruction, modification, or curtailment of the rabbitsfoot habitat and range represents a significant threat of moderate to high magnitude.

B. <u>Overutilization for commercial, recreational, scientific, or educational purposes</u>.

The rabbitsfoot was never a valuable shell for the commercial pearl button industry (Meek and Clark 1912, p. 15; Murray and Leonard 1962, p. 65), nor the cultured pearl industry (Williams and Schuster 1989, p. 23), and hence these activities were probably not significant factors in its decline. However, it was noted occasionally in commercial harvests as evidenced from musseler's cull piles (Isely 1924; Parmalee et al. 1980, p. 101). The impact of current commercial harvest on the status of the rabbitsfoot is considered to be non-significant. This species may be sought by collectors with its increasing rarity. While it can be considered a future threat, the probability of it occurring is low. Most stream reaches inhabited by this species are restricted and populations are small. Although scientific collecting is not thought or known to represent a significant threat, very small and localized populations could become impacted and possibly extirpated by over collecting, particularly if this activity is unregulated. In addition, anglers and commercial fisherman may occasionally use this species for bait. Anyone holding a fishing license in Missouri is allowed five individuals per day for use as bait.

In summary, over collection of this species appears to have been a historic impact and is non-imminent. We consider this to be a potential threat of low magnitude.

C. <u>Disease or predation.</u>

The occurrence of disease in mussels is virtually unknown. Several mussel die offs have been documented during the past few decades, including streams within the range of the rabbitsfoot (Neves 1986, pp. 8-11). Although the ultimate cause is unknown, some researchers believe that disease may be a factor (Neves 1986, p. 9). Parasites on mussels include water mites, trematodes, leeches, bacteria, and some protozoa. Although these organisms are generally not suspected to be a major limiting factor for mussel populations (Oesch 1984, pp. 16-19), a recent study provides contrary evidence. Gangloff and Feminella (2004, p. 346) suggest that reproductive output is negatively correlated with mite abundance and physiological condition (based on mantle-tissue glycogen concentration) is negatively correlated with trematode abundance.

Native Americans harvested the rabbitsfoot for food (Morrison 1942, pp. 347-351 and 357; Bogan 1990, pp. 112-114 and 136). Among mussel predators, the muskrat (*Ondatra zibethicus*) is probably cited most often (Hanson et al. 1989, pp. 15-16). Based on a study of muskrat predation on imperiled mussels in the upper North Fork Holston River in Virginia, Neves and Odom (1989, pp. 939-940) concluded that this activity could limit the recovery potential of endangered mussel species or contribute to the local extirpation of already depleted mussel populations. Predation by muskrats may represent a seasonal and localized threat to the rabbitsfoot. Galbraith et al. (2008, p. 49) hypothesized that predation may have exacerbated rabbitsfoot mortality at a site in the Little River during the 2005 Oklahoma drought. Harris et al. (2007, p. 31) reported numerous dead rabbitsfoot from muskrat middens in the Spring River, Arkansas. Although, muskrat predation appears to be in decline in many southern streams (R. Butler 2005, pers. comm.). Other mammals (e.g., raccoon, mink, otter, hogs, and rats), turtles, and aquatic birds also occasionally feed on mussels (Kunz 1898, p. 328; Neck 1986, pp. 64-65). The threat from these species is not currently deemed significant. Some species of fish feed on mussels (e.g., freshwater drum, and redear sunfish), and potentially upon young of this species. According to Zimmerman et al. (2003, p. 28), flatworms are voracious predators on newly metamorphosed juvenile mussels in culture facilities.

In summary, diseases of freshwater mussels remain largely unstudied and are not considered a current threat. Naturally occurring predation is an ongoing and, therefore imminent threat due to the limited population size of the rabbitsfoot in many extant streams and is expected to continue and remain a threat as long as low populations persist; therefore we consider predation to be a threat of low magnitude.

D. <u>The inadequacy of existing regulatory mechanisms</u>.

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Sources of non-point source pollution include timber clear-cutting, clearing of riparian vegetation, urbanization, road construction, and other practices that allow bare earth to enter streams. Current laws do not protect the habitat of the rabbitsfoot from non-point source pollution and the laws to prevent sediment entering water ways are poorly enforced. Although Best Management Practices for sediment and erosion control are often recommended or required by local ordinances for construction projects, compliance, monitoring, and enforcement of these recommendations are often poorly implemented. Furthermore, there are currently no requirements within the scope of Federal environmental laws to specifically consider the rabbitsfoot during Federal activities, or to ensure that Federal projects will not jeopardize its continued existence.

Point source discharges within the range of the rabbitsfoot have been reduced since the inception of the Clean Water Act, but this may not provide adequate protection for filter feeding organisms that can be impacted by extremely low levels of contaminants. There is no specific information on the sensitivity of the rabbitsfoot to common industrial and municipal pollutants, and very little information on other freshwater mollusks. Current State and Federal regulations regarding pollutants are assumed to be protective of freshwater mollusks; however, this species may be more susceptible to some pollutants than test organisms commonly used in bioassays. For instance, current numeric criteria for ammonia may not be protective of mussels (Augspurger et al. 2003, p. 2569). Water-quality criteria must become more stringent and pollution-prevention controls more effective for point-source pollution to have a decreasing influence on riverine habitat quality (Newton 2003, p. 2544). In addition, municipal wastewater plants continue to discharge large amounts of effluent and, in some circumstances (see section A above), in excess of permitted levels.

The rabbitsfoot has been assigned conservation status in 10 of the 15 states from which it is known (i.e., endangered status in Illinois, Indiana, Kansas, Mississippi, Ohio, Pennsylvania; threatened in Kentucky, Tennessee [assigned by Parmalee and Bogan (1998)]; special concern in Arkansas; uncategorized conservation status in Alabama). The level of protection it receives from state listing varies from state to state, but most states with extant rabbitsfoot populations prohibit the taking of mussels for scientific purposes without a state collecting permit. State regulations do not protect mussels from other threats.

In summary, existing regulatory mechanisms enforced by the state provide little direct protection of rabbitsfoot. Non-point source pollution is not regulated and the Clean Water Act does not adequately protect the habitat from degradation caused by point source pollutants. Numerous municipal wastewater treatment plants discharge large quantities of effluent into rivers or their tributaries within the rabbitsfoot range. These are long term projects that are expected to continue indefinitely. Because of the vulnerability of the remaining populations of the rabbitsfoot and the imminence of these threats, we find the inadequacy of existing regulatory mechanisms a significant threat of high magnitude.

E. Other natural or manmade factors affecting its continued existence.

The majority of the remaining rabbitsfoot populations are generally small and geographically isolated. The factor that most noticeably results in population isolation is impoundment but may also include stream reaches heavily impacted by toxic effluents and contaminated sediments. The patchy distributional pattern of populations in short river reaches makes them much more susceptible to extirpation due to the lack of recolonization from other populations (Sjögren 1991, pp. 143-144). Single catastrophic events, such as toxic chemical spills at bridges, along roads and railways and illegal or accidental point source discharges, could cause the extirpation of small, isolated rabbitsfoot occurrences. High levels of isolation make natural repopulation of any extirpated population impossible without human intervention. Population isolation also prohibits the natural interchange of genetic material between populations, an issue discussed in the following section.

The likelihood is high that some rabbitsfoot populations are below the effective population size (EPS) (Soulé 1980, pp. 162-164) required to maintain long-term genetic and population viability. Recruitment reduction or failure is a potential problem for many small rabbitsfoot populations range wide, a potential condition exacerbated by its reduced range and increasingly isolated populations. If these trends continue, further significant declines in total rabbitsfoot population size and consequent reduction in long-term viability may soon become apparent. Its present distribution and status may be indicative of the detrimental bottleneck effect resulting when the EPS is not attained. A once diffuse rabbitsfoot population occurred throughout much of the Ohio River system and the lower half of the Mississippi River Basin in scores of tributary streams. On a geological scale, there were limited barriers preventing genetic interchange among its tributary sub-populations. With the completion of hundreds of dams in the 1900s, many main stem rabbitsfoot populations were lost and tributary populations became isolated.

When the population size of a short-lived species (e.g., most fishes) in an isolated tributary falls below the threshold level of sustainability, it would theoretically die out within a decade or so after impoundment. Conversely, the population size of a long-lived species, such as the rabbitsfoot, would potentially take decades to become extirpated post-impoundment even if complete recruitment failure occurred. Without the level of genetic interchange the species experienced historically (i.e., without barriers such as reservoirs), small isolated populations that may now be comprised predominantly of adult specimens could be slowly dying out. Even given the totally improbable absence of other anthropogenic threats, we may lose these disjunct populations simply due to the devastating consequences of below-threshold EPS. Evidence indicates that general degradation of many isolated stream reaches is continuing to result in ever decreasing patches of suitable habitat. Thus, these threats act insidiously to contribute to the decline of rabbitsfoot populations over time. The fact that only 50 primarily disjunct streams among 139 historically continue to harbor populations of the rabbitsfoot is likely partial testimony to the principle of EPS and its role in population loss.

The rarity displayed by most rabbitsfoot populations makes it problematic for resource managers to incorporate many of the genetic issues associated with maintaining a high level of genetic diversity. Neves (1997, p.6) warned that “if we let conservation genetics become the goal rather than the guidelines for restoring and recovering mussel populations, then we will be doomed to failure with rare species.” Habitat alteration and not lack of genetic variability were the driving forces of population extirpation, a conclusion also reached by others (Caro and Laurenson 1994, pp. 485-486). Nevertheless, issues raised in this section should be a major concern to maintain high levels of genetic heterozygosity when attempting to conserve imperiled populations and recovering the rabbitsfoot. Treating disjunct populations of this widely ranging species as a metapopulation, Neves (1997, p. 6) explains, would facilitate conservation management while increasing recovery options for the translocation of adults, infected host fishes, and propagated juveniles to establish and maintain viable populations. Due to small population size and resultant reduction of the reservoir of genetic diversity within populations, care should be taken to maximize genetic heterogeneity to avoid inbreeding depression

(Templeton and Read 1984, p. 196) and out breeding depression (Avise and Hamrick 1996, p. 465) whenever feasible in translocation and propagation efforts.

Various invasive (i.e., nonnative) species of aquatic organisms are firmly established in the range of the rabbitsfoot. The invasive species that pose the most significant threat, albeit limited to commercially navigable waterways in the northern portion of the rabbitsfoot range, is the zebra mussel, *Dreissena polymorpha* (Pallas, 1771). The zebra mussel invasion poses a threat to mussel faunas in many regions, and species extinctions are expected as a result of its continued spread in the eastern United States (Ricciardi et al. 1998, p. 613). Strayer (1999b, pp. 75-80) reviewed in detail the mechanisms in which zebra mussels impact native mussels. Growth rates of a riverine mussel, the ebonyshell, *Fusconaia ebena* Lea 1831, have been reduced in the lower Ohio River in years of heavy zebra mussel infestation (Payne and Miller 2002, p. 45). They may also reduce food concentrations to levels too low to support reproduction or even survival of native mussels in extreme cases. Other ways in which zebra mussels may impact native mussels is potentially through filtering their sperm and possibly even their glochidia from the water column. Habitat for native mussels may also be degraded by large deposits of zebra mussel pseudofeces (waste material passed out of the incurrent siphon, not the anus and excurrent siphon) (Service 1997, p. 11).

Overlapping much of the current range of the rabbitsfoot, zebra mussels have been detected and/or are established in rabbitsfoot streams (e.g., Ohio, Allegheny, Green, Tennessee, White Rivers; French, Bear Creeks, Verdigris River). Populations appear to be maintained primarily in streams with barge navigation. A source population is apparently instrumental in the maintenance of zebra mussel populations in downstream areas (Stoeckel et al. 2003, p. 334). Zebra mussels may have directly reduced rabbitsfoot populations in the lower Ohio River. Their density in the lower Tennessee River remained low until 2002, when they became abundant enough to be measured quantitatively but have since plummeted (J.T. Garner 2005, pers. comm.). As zebra mussels may maintain high densities in big rivers, large tributaries, and below infested reservoirs, rabbitsfoot populations in these affected areas have the potential to be significantly impacted. In addition, there is long-term potential for zebra mussel invasions into other systems that currently harbor rabbitsfoot populations.

However, evidence is mounting in some northern streams where there is no barge navigation (e.g., French Creek, Tippecanoe River) and southern ones with barge traffic (e.g., Tennessee River) that the zebra mussel threat may be minimal (B.E. Fisher, 2009, J.T. Garner, T.A. Smith 2005, pers. comm.).

The Asian clam (*Corbicula fluminea* Müller, 1774) has spread throughout the Mississippi River Basin since its introduction into the basin in the mid-1900s. This species has been implicated as a competitor with native mussels, particularly juveniles, for resources such as food, nutrients, and space (Neves and Widlak 1987, p. 6; Leff et al. 1990, p. 414). According to Strayer (1999b, p. 82), dense populations of Asian clams may ingest large numbers of unionid sperm, glochidia, and newly-metamorphosed juveniles. He also thought they actively disturb sediments, so dense populations may reduce habitat for juvenile native mussels. Periodic die offs of Asian clams may produce enough ammonia and consume enough dissolved oxygen to kill native mussels (Strayer 1999b, p. 82). Yeager et al. (2001, pp. 257-258) determined that high densities of Asian clams negatively impacted the survival and growth of newly metamorphosed juvenile mussels and thus reduced recruitment. They proved from laboratory experiments that Asian clam readily ingested glochidia, clam density and juvenile mussel mortality were positively correlated, growth rates were reduced with the presence of clams, and juvenile mussels were displaced in greater numbers downstream in laboratory tests with clams. A study by Vaughn and Spooner (2005) indicated that the Asian clam was unable to successfully invade habitat patches with high unionid biomass and species richness. This indicates that the clam may not cause native mussels in dense beds to decline when it invades their habitat. However, an Asian clam population that thrives in previously stressed, sparse mussel populations might cause some of the problems discussed above exacerbating native mussel imperilment. Asian clam inhabits most streams in the U.S.

Native to China, the black carp (*Mylopharyngodon piceus*) is a potential threat to the rabbitsfoot (Strayer 1999b, p. 89). Nico and Williams (1996, pp. 14-37) prepared a risk assessment of the black carp and summarized all known aspects of its ecology, life history, and intentional introduction (since the 1970s) into North America. A molluscivore (mollusk predator), the black carp has been proposed for widespread use by aquaculturists to control snails, the intermediate host of a trematode (flatworm) parasite affecting catfish in ponds in the Southeast and lower Midwest. They are known to feed on various mollusks, including unionid mussels, in China. They are the largest of the Asiatic carp species, reaching more than 4 feet in length and achieving a weight in excess of 150 pounds (Nico and Williams 1996, p. 6). During a 1994 flood, several black carp escaped from an aquaculture facility in Missouri. A supposedly sterile black carp specimen was caught in March 2003 in an oxbow of the Mississippi River near the mouth of the Ohio River, very near the extant rabbitsfoot population in the Ohio (MICRA 2003c, pp. 4-5). During a 2009 effort to eradicate the exotic snakehead fish from a tributary to the White River in Arkansas, sterile black carp were collected in rotenone samples (C. Davidson, 2009, pers. comm.). Other escapes into the wild by sterile and nonsterile black carp is deemed imminent by conservation biologists. If this species invades streams with mussel communities, sterile or non-sterile individuals could wreak havoc on already stressed native mussel populations. The black carp was listed by the Service as an injurious species of wildlife in October, 2007 (U.S. Fish and Wildlife Service 2007, pp. 59019-59035).

The round goby (*Neogobius melanostomus*) is another alien invader fish species released in the 1980s into the Great Lakes in ballast waters originating in southeastern Europe (Strayer 1999b, pp. 87-88). They are well established in much of the Great Lakes, and will likely move south through the Mississippi River system as has the zebra mussel (Strayer 1999b, p. 88). A voracious carnivore, despite its size (generally less than 10 inches in length), the round goby will eat a wide variety of foods, including native juvenile mussels and small fishes that potentially serve as hosts. Round gobies also are aggressive competitors, and may eliminate or reduce populations of sculpins and darters (Strayer 1999b, p. 88). The arrival of round gobies may therefore have important indirect effects on unionid communities through negative impacts to their host fishes.

Additional invasive species may become established in the United States in coming years, and could disrupt native species distributions and abundance (Strayer 1999b, pp. 88-89). These include *Limnoperna fortunei*, a freshwater mussel from Southeast Asia that fouls solid objects as does the zebra mussel. This species has already spread to Japan and South America, and "probably will have strong effects" on native unionids (Strayer 1999b, p. 89). Alien species potentially carry diseases and parasites that may be devastating to the native biota. "Because of our ignorance of mollusk diseases and parasites, it is imprudent to conclude that alien diseases and parasites are unimportant (Strayer 1999b, p. 88)".

Global climate change poses a new potential threat to the rabbitsfoot. Current climate change predictions indicate warmer air temperatures, more intense precipitation events, and increased summer drying [U.S. Global Change Research Program (GCRP) 2009]. These changes are likely to have complex and unpredictable effects upon freshwater biota, but some potential effects related to extreme low and high water events and overall temperature changes to mussel populations are intuitive. Increased occurrence of both major flood events and drought would likely affect remaining populations of the rabbitsfoot. Additionally, the human response to drought would be increased water withdraw from streams for crop irrigation, and thus, would further decrease water levels in streams intensifying the effects of drought.

Water temperatures would increase in streams with the predicted increases in air temperatures (GCRP 2009). More periods of drought would intensify this effect within streams and smaller streams in particular. Because freshwater mussels are ectotherms (body temperature depends on the environment), their physiological processes and reproductive success are constrained and controlled by water temperature. Mussels appear to have varying temperature optima, which strongly influences filtration rates, excretion rates and other processes (Sponner and Vaughn 2008). Therefore, increased water temperatures would be expected to cause changes in the distribution and abundance of species and local extirpations could occur. Species would be expected to respond differently to climate change, and therefore, it is uncertain whether changes in water temperature would affect the rabbitsfoot.

Ficke et al. (2005) described the general potential effects of climate change on freshwater fish populations world-wide. Overall, the distribution of fish species is expected to change including range shifts and local extirpations. Because freshwater mussels are entirely dependent upon a fish host for successful reproduction and dispersal, any changes in local fish populations would also affect freshwater mussel populations. Therefore, mussel populations will reflect local extirpations or decreases in abundance of fish species. Species such as the rabbitsfoot that relies on suitable fish host species also may be affected with changes in the fish community.

With increases in air temperature, the range of some species may gradually shift northward to stay within their optimal temperature. However, species like the rabbitsfoot, with fragmented suitable habitat and populations, may have a more difficult time adjusting their ranges or may not be able to respond to changing conditions at all. All streams within the range of the Neosho mucket flow south from rivers in Arkansas, Kansas, Missouri and Oklahoma that eventually flow into the Arkansas River. Given this drainage pattern, a gradual shift in the range of the species northward to a cooler climate would not be possible for the species.

In summary, a variety of natural and manmade factors historically or currently threatens, or has the potential to threaten the rabbitsfoot. The continued existence of this species is threatened by lack of recruitment and genetic isolation. Non-indigenous species, such as zebra mussel, black carp and Asian clam, have potentially adversely affected populations of the rabbitsfoot and its host fish, thereby affecting recruitment, and may directly affect the rabbitsfoot through competition for resources. It is currently not possible to remove non-indigenous species. These are self sustaining populations that are expected to persist as a threat indefinitely. As the climate may change, species across the United States are expected to undergo large shifts in range (GCRP 2009). While it is likely that the observed increase in global average temperatures is due to the observed increase in human-induced greenhouse gas concentrations, the best scientific data available today does not allow us to draw a causal connection between specific greenhouse gas emissions and effects posed to the rabbitsfoot, nor is there sufficient data to establish that such effects are reasonably certain to occur.

Therefore, we have determined that other natural and manmade factors such as lack of recruitment combined with and exacerbated by invasive species and potential global climate change effects pose an imminent threat to the remaining marginal and small populations of the rabbitsfoot. The magnitude of these threats is high.

CONSERVATION MEASURES PLANNED OR IMPLEMENTED

The Service's Partners for Fish and Wildlife program has funded millions of dollars in projects to private landowners to enhance riparian habitat in many streams with rabbitsfoot populations. For instance, specific watershed level projects that have benefited habitat for the rabbitsfoot include the critically important populations in the Green and Duck Rivers. Other funding sources for rabbitsfoot habitat restoration and conservation include CWA Section 319, U.S. Department of Agriculture Natural Resource Conservation Service programs (e.g., Environmental Quality Incentives Program, Wildlife Habitat Improvement Program, Conservation Reserve Enhancement Program [CREP]), Private Stewardship Grant, National Fish and Wildlife Foundation, and numerous other Federal and State programs are potential sources of money for various projects that benefit mussels. For instance, a huge CREP grant of $110 million has been secured by Kentucky to take up to 100,000 acres of riparian lands out of agricultural production in the upper Green River watershed. Efforts will focus on areas that should be of direct benefit to the Green River's substantial rabbitsfoot population. Rivers designated as TNC bioreserves, such as the Strawberry River which is on the CWA Section 303(d) list for sedimentation impairment (TNC 2004, p. 1), will often obtain Section 319 grants for sediment remediation activities.

TNC, Western PA Conservancy, and Fish Creek Trustee Council are conducting sediment remediation work in several TNC bioreserves, while the latter two NGOs implement similar activities in French Creek and Fish Creek, respectively. The Green River Bioreserve TNC staff contracted with the Corps to explore ways in which flow releases from the Green River Reservoir Dam can be modified to improve seasonal flow patterns and instream habitat in the Green. These efforts should improve conditions for the rabbitsfoot and a host of other imperiled aquatic organisms in the upper Green River.

Reservoir releases from TVA (Scott et al. 1996; Ahlstedt et al. 2004, p. 35) and other (Poff et al. 2003, pp. 298-300) dams have been modified in recent years improving water quality and habitat conditions in many tailwaters. Ostby (2005, pp. ii-iv) and Ostby and Neves (2007, pp. iii-v) evaluated substratum and flow preferences for rare freshwater mussels in the upper Tennessee River drainage developing and refining flow criteria. Flow improvements below dams have enabled partners to attempt the reintroduction of extirpated federally listed and other imperiled species. Although current reintroduction efforts in TVA tailwaters have focused almost entirely on listed species, activities are expanding to include other imperiled taxa such as the rabbitsfoot.

The Service completed a biological opinion in 2006 for TVA Tennessee River operations and maintenance activities. As a result, TVA will develop and implement monitoring programs to establish baselines and track changes in abundance, density, and frequency of several imperiled fishes and mussels. TVA will modify operations in the Elk River associated with hydropower generation at Tims Ford Dam with the goal of warming spring and summer tailwater temperature and lessening the water level fluctuations year round. These new operations should add approximately 30 river miles of good habitat in the Elk River upstream from Fayetteville, and these operations will improve habitat in the entire tailwater. TVA also has committed to water quality and biological monitoring for a period of at least 10 years (S. Chance 2008, pers. comm.).

Service biologists are initiating Safe Harbor Agreements (for listed species) and Candidate Conservation Agreements with Assurances (for candidate species) with private landowners to conserve populations of aquatic organisms. When populations of the rabbitsfoot occur with targeted listed and candidate species under these protection measures, as they do in the Middle Fork Little Red, Ouachita, Saline, and Caddo rivers (C.L. Davidson 2005, pers. comm.), they will benefit as well. The Ohio River Valley Ecosystem (ORVE) team's Mollusk Subgroup determined the need for and is conducting a status review of the rabbitsfoot. Ecosystem teams and other partners will act as some of the individuals that will identify future funding needs and sources for the rabbitsfoot.

The State of Kansas has designated critical habitat in river reaches where the rabbitsfoot is extant and for numerous additional river miles of currently unoccupied historical habitat (e.g., most of the length of the Neosho River, two short disjunct reaches of the Spring River) (Obermeyer 2000, p. 10). Kansas has also established a mussel refuge on the Neosho and Verdigris rivers which serves to protect mussels from exploitation (Obermeyer 1997, p. 445, B. Simmons 2009, pers. comm.). Kansas plans to use ESA section 6 funds to re-establish rabbitsfoot at a mussel refuge site located downstream of Oolagah Reservoir in the Verdigris River. Refuges have also been established in other states (e.g., Alabama, Kentucky, and Tennessee).

The Pharmaceutical Research and Manufacturers of America signed a formal agreement with the Service and the American Pharmacists Association on March 17, 2008, to help protect the nation's fish and aquatic resources from the improper disposal of medication. The campaign dubbed "SmarxT Disposal" will inform people on how to safely dispose of medicines in the trash, and highlight the environmental threat posed from flushing medicines down the toilet (http://www.smarxtdisposal.net).

SUMMARY OF THREATS

Significant habitat loss, range restriction, and population fragmentation and size reduction have rendered the rabbitsfoot vulnerable to extinction. The rabbitsfoot has disappeared from five of six rivers in the Lower Great Lakes sub-basin, 46 of 64 rivers in the Ohio River system, 10 of 12 rivers in the Cumberland River basin, 14 of 19 rivers in the Tennessee River system, 2 of 5 rivers in the Lower Mississippi River sub-basin, 3 of 12 rivers in the White River system, 4 of 8 rivers in the Arkansas River system, and 4 of 11 rivers in the Red River system. Of the 139 known historical populations, 50 remain, but only 10 populations are considered to be viable in the long-term. Population declines continue in most of the species' range, and numerous threats, including water quality degradation, loss of stable substrates, sedimentation, channelization, gravel mining, dredging, and impoundments, are impacting the few remaining sustainable extant populations. The small size of most of the remaining rabbitsfoot populations exacerbates the threats and adverse effects of chance events to rabbitsfoot.

Tremendous habitat losses measured in the thousands of miles have occurred in large stream reaches from which the rabbitsfoot is now considered extirpated (e.g., Muskingum, Elk, Scioto, Little Miami, Licking, East Fork White, Cumberland, Holston, Clinch, Sequatchie, Buffalo [Duck River system], Verdigris Rivers), in addition to thousands of additional miles in scores of smaller streams. Further range reductions have occurred within certain large rivers having generally small and very restricted extant populations (e.g., it is considered extirpated from ~95% of the 981 RM Ohio River main stem, ~95% of the 475 RM Wabash River, ~95% of the 650 RM Tennessee River, ~85% of the 690 RM White River, ~95% of the 460 RM Neosho River). The amount of habitat loss and the extirpation of this species from thousands of miles of habitat within its range indicate catastrophic population losses as well. Total range reduction and overall population loss for the rabbitsfoot realistically approaches--if not exceeds--90%.

Threats to the continued existence of rabbitsfoot include exotic species, especially zebra mussels; delivery and deposition of fine sediments; small population sizes; isolation of populations; livestock grazing; wastewater effluents; mine runoff; unstable and coldwater flows downstream of dams; gravel mining; channel dredging; and potential global climate change effects. In addition, the fish host of rabbitsfoot is unknown for the eastern portion of its range; thus, propagation to reestablish the species in restored habitats and to maintain non-reproducing populations and focused conservation of its fish host are not possible. Although there are ongoing attempts to alleviate some of these threats at some locations, there appear to be no populations without significant threats and many threats are without obvious or readily available solutions.

We have carefully assessed the best scientific and commercial information available regarding the past, present, and future threats faced by the rabbitsfoot in determining this assessment. The present distribution and abundance of the rabbitsfoot are at risk given the ongoing impacts to this subspecies. Therefore, based on this evaluation, it is appropriate that the rabbitsfoot be designated as a candidate species.

RECOMMENDED CONSERVATION MEASURES

1. More watershed-scale, community-based riparian habitat restoration projects should be initiated in high biodiversity streams harboring the rabbitsfoot. By establishing bioreserves and other large-scale projects, significant levels of habitat can be restored and protected for the betterment of imperiled mussel resources.

2. During Interagency Consultations (Section 7 of the Act), or in the development of Habitat Conservation Plans, minimization and mitigation of adverse effects to listed and candidate mussel species should consider conservation measures, in addition to relocation, which further species recovery goals.

3. The assistance of various stakeholders, working at the ecosystem and watershed levels, will be essential for the conservation and restoration of rabbitsfoot populations. More importantly, the support of the local community, including agricultural, silvicultural, mining, construction, and other developmental interests; local individuals; and landowners, will be essential in order to meet rabbitsfoot recovery goals.

4. Shute et al. (1997, pp. 445-462) also outlined management and conservation considerations for imperiled mussels such as the rabbitsfoot, while incorporating ecosystem management into the equation. These broadly included:

    a. Prioritizing aquatic ecosystems needing protection,
    b. Identifying all potential agencies and organizations within a watershed,
    c. Prioritizing ecosystem threats,
    d. Identifying strategies to minimize or eliminate threats, and
    e. Educating stakeholders.

5. Obermeyer (2000, pp. 1-52) wrote a recovery plan for the rabbitsfoot (and three other imperiled mussels) in Kansas. He summarized various recovery criteria, recovery implementation tasks, and conservation programs to assist private

landowners in habitat protection. Many of the activities covered would be beneficial to the species if implemented range wide. They are summarized below, but are not limited to:

a. Offer incentives to landowners to protect and/or restore habitat,
b. Reduce and/or minimize threats from a broad array of sources,
c. Develop partnerships,
d. Utilize existing legislation and regulations to protect species and their habitats,
e. Conduct population monitoring, life history studies, and fund research priorities directed at species recovery, and
f. Promote outreach and education programs related to watershed stewardship and the importance of mussels.

6. The overall conservation status of the rabbitsfoot would improve if more extant populations could be maintained at viable levels or if populations were to become re-established where extirpated. Certain extant rabbitsfoot populations would benefit from population augmentation. The species would clearly benefit from population reintroduction into select streams and stream reaches with appropriate habitat in its historical range.

7. Threats analyses should be undertaken in at least those watersheds with significant extant rabbitsfoot populations. The purpose of a threats analysis is to determine the entire suite of stressors to a species and its habitat, to locate the sources of the various stressors, and to outline management activities to eliminate or at least minimize each stressor.

8. More studies are needed to determine the rabbitsfoot glochidia host organisms across its entire range (Obermeyer et al. 1997b, p. 52).

9. Little information is available with regard to other aspects of rabbitsfoot life history. Additional information will be needed in order to successfully implement the recovery tasks. In addition, essential rabbitsfoot habitat (e.g., relevant physical, biological, chemical components) for all life history stages needs to be elucidated.

10. Research is needed to determine the sensitivity of each rabbitsfoot life history stage to various contaminants, particularly pharmaceutical chemicals.

11. Drug delivery methodologies for humans must be modified to reduce chemical concentrations in wastewater effluents (significant percentages may be excreted in urine) and WWTPs need to be designed to remove pharmaceuticals to protect aquatic organisms. .

12. Studies on the specific effects of other threats (e.g., genetic bottlenecks from population isolation) would be highly beneficial to the rabbitsfoot.

13. Neves and Ahlstedt (2001, pp. 70-72) outlined mussel recovery programs focusing on propagation and translocation of laboratory-reared progeny to the wild. To this end, propagation technology should be developed for the rabbitsfoot once its hosts have been determined. Any attempted propagation program should generally adhere to policy established by the Service for propagation of federally listed species (Service and National Marine Fisheries Service 2000, pp. 56916-56922). Such an effort was funded in 2008 to reintroduce rabbitsfoot into the upper Verdigris River in Kansas using individuals from the lower reaches of the river in Oklahoma (B. Simmons 2009, pers. comm.).

14. In addition to focusing efforts on elucidating factors contributing to the rabbitsfoot decline, research should focus upon various factors that contribute to the maintenance of sizable healthy populations. For instance, there is evidence that minimum flow releases from impoundments have been associated with relatively high levels of recent mussel recruitment in the Duck (Ahlstedt et al. 2004, p. 35) and Green (J.B. Layzer 2004, pers. comm.) Rivers. Other physical (e.g., fluvial geomorphology, habitat stability, well-oxygenated interstitial habitat) and biological (e.g., food quality and quantity, host fish abundance and seasonality, mussel density needed to assure high fertilization rates, demographic and genetic characteristics, EPS) factors potentially involved in the maintenance of large healthy populations should be investigated (Strayer et al. 2004, pp. 430-438). A thorough understanding of these factors is crucial not only for maintaining existing populations but ultimately in establishing reintroduced ones.

15. A set of biological, ecological, and habitat parameters will need to be developed to determine if an extant rabbitsfoot population will be suitable for species augmentation and reintroduction. This is particularly important for separating those populations that are more readily protected and with real recovery potential from those considered having overwhelming threats and insignificant recovery potential.

16. Reintroduction sites should include habitat suitability, substrate stability, presence of host fishes, potential site threats, and any other limiting factor that might decrease the likelihood of long-term benefits from population reintroduction efforts. Augmentation and reintroduction activities should not be conducted at totally unprotected sites or at sites with significant uncontrollable threats.

17. A range wide study on the rabbitsfoot should be conducted to determine if there are any populations that may be taxonomically or ecologically distinct and/or in need of recognition for conservation and recovery purposes

18. Developing and implementing cryogenic techniques to preserve rabbitsfoot genetic material until such time as conditions are suitable for reintroduction may

be beneficial to recovery. If a population were lost to a catastrophic event, such as a toxic chemical spill, cryogenic preservation could allow for the eventual reestablishment of the population using genetic material preserved from that population.

19. Survey work to search for potentially new rabbitsfoot populations, presumed extirpated populations, and to assess the status of other populations would be beneficial for conservation management and recovery efforts.

20. A monitoring program should be developed and implemented to evaluate conservation and recovery efforts and monitor rabbitsfoot population levels and habitat conditions.

21. A comprehensive Geographic Information System database to incorporate information on the species' distribution, population demographics, and various threats identified during monitoring activities should be established. Such a database is being incorporated for the Bear Creek mussel population (S.W. McGregor 2005, pers. comm.).

The rabbitsfoot is included in the Alabama, Arkansas, Illinois, Indiana, Kansas, Kentucky, Louisiana, Missouri, Mississippi, Oklahoma, Ohio, and Tennessee State Wildlife Action Plans as a species of conservation concern. The species has been extirpated from Georgia and West Virginia, which likely accounts for its omission from their plan. Pennsylvania does not have a state agency responsible for invertebrates. Therefore, they have contracted with a third party to conduct an assessment/inventory of invertebrates and determine their state status.

LISTING PRIORITY

THREAT			
Magnitude	Immediacy	Taxonomy	Priority
High	Imminent	Monotypic genus	1
		Species	2
		Subspecies/population	3
	Non-imminent	Monotypic genus	4
		Species	5
		Subspecies/population	6
Moderate to Low	**Imminent**	Monotypic genus	7
		Species	8
		Subspecies/population	**9***
	Non-imminent	Monotypic genus	10
		Species	11
		Subspecies/population	12

“Yes” Have you promptly reviewed all of the information received regarding the species for the purpose of determining whether emergency listing is needed?

RATIONALE FOR LISTING PRIORITY NUMBER:

Magnitude: The number of stream populations with the sum of stresses ranking high was approximately equal to those with a moderate magnitude. Due to the number of extant populations, we consider the threats to rabbitsfoot to be of moderate magnitude. The rabbitsfoot has been extirpated from 89 of 139 streams of historical occurrence, representing a 64 percent decline. Ten sizable populations are still viable and several small populations have limited recent recruitment. Threats to the continued existence of rabbitsfoot include impoundments, contaminants, sedimentation, nutrient enrichment, channel alteration such as dredging and maintenance operations, exotic species, water withdrawal, flow regime alteration, demographic isolation, and mining activities. Although there are ongoing attempts to alleviate some of these threats at some locations, most extant populations still face significant threats and declining populations. In addition the fish host of rabbitsfoot is only known for the range west of the Mississippi River; thus, propagation to reestablish the species in restored habitats, maintain non-reproducing populations, and focus conservation on its fish host across most of its range is not possible. Further complicating recovery efforts, differences observed in morphology and reproductive timing in populations west of the Mississippi River indicate that some, if not many, rabbitsfoot populations should be managed as separate units.

Imminence: The threats to the rabbitsfoot are imminent. This species has experienced a significant reduction in range and most of its extant populations are declining and/or isolated. The extirpation of this species from 89 streams within its historical range indicates that substantial population losses have occurred. Threats that have occurred in the past still continue to occur and have the potential to continue into the future. The immediacy of the sum of stresses was imminent in 44 of 50 extant stream populations. Changes in population dynamics, such as reduced genetic diversity and limited natural reproduction, are imminent due to the drastic range reduction. While ten sizable populations are thought to be viable and several smaller populations are thought to have limited recruitment, the compilation of current distribution, abundance, and trend information indicate that threats are ongoing and, therefore, imminent.

Yes Have you promptly reviewed all of the information received regarding the species for the purpose of determining whether emergency listing is needed?

Is emergency listing warranted? No. The species is not nearing extinction, but warrants protection in order to recover populations to sustainable levels and reverse population declines and extirpations.

DESCRIPTION OF MONITORING

The July, 2005, status assessment for the rabbitsfoot (Butler 2005, pp. 160-200) provides current distributional history (historical, considered extirpated and extant populations) in Appendices 1 to 3. These appendices also include a chronology of occurrence, state, authority, year of last occurrence, whether the population is recruiting, its viability status, and overall population trend. The Service sent out data requests for recent rabbitsfoot data since Butler (2005) on February 16, 2008, January 16, 2009, February 24, 2010, and received 63 responses that included recent data on rabbitsfoot. Given the comprehensive nature, recent completion, and number of species experts referenced in the status assessment, we believe that an appropriate level of monitoring occurred to update the status of this species.

COORDINATION WITH STATES

The latest status assessment was completed in July, 2005 (Butler 2005). Comments were received during the status assessment by experts representing states within the historic range. The Service sent a request for rabbitsfoot data since Butler (2005) to the unio list serve, which is list serve maintained by the Freshwater Mollusk Conservation Society, on February 16, 2008, January 16, 2009, and February 24, 2010. To the best of our knowledge, malacologists representing state and federal agencies and non-governmental organizations subscribe to the list serve. The Service felt that this was the best method to effectively and efficiently request recent rabbitsfoot data. The Service received recent data and support for elevating the species from 63 respondents with expertise on the species. Rabbitsfoot is included in 12 of 15 state Comprehensive Wildlife Conservation Strategies. The species is extirpated from West Virginia and Georgia and thus is not included in their plans. No state agency in Pennsylvania has jurisdiction over invertebrates and thus rabbitsfoot is not included in their plan. However, they have contracted with a third party to develop a plan for invertebrates that is expected to include rabbitsfoot. State malacologists and biologists working with mussels have been supportive of elevating the species to candidate status. No negative responses have been received from the states regarding elevation of rabbitsfoot.

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APPROVAL/CONCURRENCE: Lead Regions must obtain written concurrence from all other Regions within the range of the species before recommending changes to the candidate list, including listing priority changes; the Regional Director must approve all such recommendations. The Director must concur on all additions of species to the candidate list, removal of candidates, and listing priority changes.

Approve: Janet Mizzi ____________________ June 15, 2010

for Regional Director, Fish and Wildlife Service Date

Concur: _____________________________________ ______

Director, Fish and Wildlife Service Date

Do not concur: _____________________________________ ______

Director, Fish and Wildlife Service Date

Director's Remarks:

Date of annual review: March 12, 2010

Conducted by: Chris Davidson - Conway, Arkansas FO